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This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

MOISTURE INDUCED PROBLEMS IN NHA HOUSING

PART 1 OF A 3 PART SERIES

ANALYSIS OF FIELD SURVEY RESULTS AND PROJECTIONS OF FUTURE PROBLEMS

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Caution

The analyses, interpretations and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation, which assisted in the study and its publications. The results of the study are published for information purposes and the reader is cautioned that the statistical and scientific data generated herein are derived from a study of a select few Canadian moisture-troubled homes.

Extrapolation of this data to most houses in Canada and to houses in other countries and climates may be feasible, provided that the vagaries of climates and the behaviour of housing systems and building materials in those areas are understood.

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EXECUTIVE SUMMARY

1.0 Introduction

This report summarizes the analysis of a field investigation of 201 moisture damaged NHA financed housing units. The analysis was Canada-wide and the sample was selected in accordance with the geographic distribution of reported problems.

This document forms part of a larger project investigating the incidence and causes of this problem in NHA financed units.[1)]

Specifically, this report contains the following:

- A description of the field survey data base.
- The results of an analysis of the field survey, indicating various factors expected to be instrumental in causing the problem.
- The results of the analysis of the problems as reported nationwide to various agencies (primarily CMHC offices and manufacturers of siding products).
- A prediction of the total future incidence of moisture related problems in NHA housing.

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1) File 176-4-25

2.0 Field Survey Data Base

The field survey data file contains a potential 324 variables for 201 NHA financed houses. These variables relate specifically to two questionnaires, one dealing with house occupant data and the second dealing with the physical condition of the house including site specific meso-climatic data.

The data file was further stratified by subregion to correspond, as far as possible, with the availability of detailed meso-climatic data.

Problems observed can be "classified" as follows:

- buckling and warping of siding and other siding problems
- high moisture readings in sheathing
- mould and mildew within the house
- high moisture readings within the wall system
- high levels of window condensation and window frame damage
- mould, mildew and high moisture readings in the attic space

3.0 Factors Expected To Be Instrumental In Moisture Problems or Damage To Housing Units

Problem houses investigated were unique in that the following characteristics differentiated them from the general Canadian housing stock.

	Problem Houses	Can. Average
Household Size	4.1	2.9
RH* First Floor	48.6%	35%
RH* Second Floor	49.8%	35%
Average Year Constructed	1975	older**
Percent of Units with Electric Heat	81%	not known**

---

* Relative Humidity

** Data Not Available for Reasonable Comparison

From a statistical analysis, factors which appear to contribute to the severity of moisture related "problems", in the NHA financed houses investigated are, as follows:

o Problems in the siding and sheathing complex appear to be related to a climatic condition found primarily in Newfoundland, with poor drying conditions during the spring season, low temperatures (lower than all of Canada in the drying season except for Northern Manitoba[1]), a high incidence of driving rain, and low energy gain from the sun. In other words, the wall system is continually "stressed" (i.e. exposed to moisture), both from the inside (lifestyle) and outside (weather), without the opportunity of drying out.

It must be recognized that all units inspected had a large number of occupants and inside Relative Humidity (RH) levels well above normal Canadian averages. The data, however, fails to support the concept that inside (lifestyle related) conditions significantly affect the severity of the observed siding problem.

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1) Note: Housing in the Yukon and Northwest Territories were not investigated as problems from this area were not reported although some are known to exist.

- Mould and mildew, whether on the first or second floor, appears to be related to high levels of internal moisture generation. Where this moisture comes in contact with a cool wall, condensation can be expected. The fact that problems are observed in areas of high wind exposure is significant in that the cooling effect of the wind, as it blows into the wall cavity is, probably, one of the important contributing factors. The observed high incidence of driving rain is also important in that this condition prevents the wall from drying out. Although the amount of solar gain is shown to be statistically significant to the severity of this condition, it should be recognized that mould and mildew tends to occur near the highest ceiling, in the shaded area under the soffit where heat gain from direct solar radiation is limited. Although a statistical correlation was found, the presence or absence of solar gain may, therefore, not be a critical factor.

- Window Condensation was observed in two very different weather regions. In the very cold areas, such as Thompson (high solar gain, low driving rain), problems were caused by frost on windows melting when the sun warms up the windows during the day. Problems were also observed on the west coast, especially in the Vancouver/Victoria area. Here, single glazing contributed significantly to the problem.

- Potential Exterior Wall problems appeared to be related to climate, particularly cold weather. Higher incidence of the problem on the second floor is indicative of exfiltration on the second floor. It is also important to note that reinsulation (warmer wall cavity) seems to have aggravated the condition.

- Two different conditions were observed in the attic. Since mould and mildew growth requires a combination of warm conditions and moisture, a significant correlation between warmer weather should be expected. Although high solar gain adds to the warmer conditions in the attic space, it also tends to dry out the area (especially in Thompson where vapour pressures are very low). These two factors probably counteract each other. High vapour pressures associated with generally warmer temperatures lead to high RH conditions (confirmed by readings in attics with a major incidence of mould and mildew). Moisture, required for mould growth, is internally generated and, coupled with poor attic ventilation, appears to be a major cause of the problem.

  High moisture readings in attic structural members are, however, associated with a completely different weather regime. Colder weather, low solar gain and driving rain (Newfoundland weather) are all strongly associated with this problem. Generally moist attic conditions are expected. In this case, wet insulation is the result of water dripping from the sheathing. As with the mould and mildew, this type of problem was found to be associated with poor attic ventilation.

4.0 Future Expected Problems

If no corrective action is taken, the reported cases of moisture related problems can be expected to increase as units age and continue to be exposed to the factors causing the problem. for NHA financed units constructed up to and including 1981, the following distribution of problems is expected:

Distribution of Moisture Induced
Problems Expected in NHA Housing

Region	Current Problems	Problems Not Yet Reported1)	Total	Potential Universe2)
Newfoundland	2 853	365	3 218	10 400
Maritime Provinces	478	86	564	32 800
Quebec	1 048	270	1 118	164 000
Ontario	1 848	270	2 118	276 000
Prairie Provinces	1 862	271	2 133	135 400
British Columbia	2 171	323	2 494	71 300
TOTAL	10 260	1 385	11 645	689 900

In addition to the foregoing, if no changes are made in construction practices, additional problems are expected in units constructed in 1982 and later. The magnitude of this problem is related to construction volumes and to regional distribution.

If, as an example, NHA financed starts remain at 1981 levels (with similar regional distributions - 28 500 starts) moisture problems can be expected in 1.6% or 460 of those units. If, however, starts increase to an average of 1970-1981 levels (88 000 starts), problems can be expected in 1.4% or 1 220 of those units. The difference being the result of the differing regional distribution of NHA housing starts.

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1) These are problems in recently constructed housing stock that have not yet been noticed and reported.

2) NHA housing units constructed from 1973 to 1981.

The above assumes that housing construction practices do not change. Should efforts be made to tighten housing units even further, these projections may well be conservative.

5.0 Conclusion

It is clear that many of the causal factors relate both to lifestyle and climatic conditions. Although lifestyle could be altered through education and public awareness programs, dominance of weather as a causal factor indicates that construction practices and details must be examined, and altered if future moisture related problems are to be avoided.

It should also be noted that the survey and the statistical analysis relates specifically to the Canadian climate and to Canadian building practices. This fact should be recognized in the interpretation of this study.

1.0 INTRODUCTION

The purpose of the analysis detailed in this report is to correlate the reported incidence and geographic distribution of moisture induced problems in NHA housing[1)] with the findings of an extensive field investigation of 201 moisture troubled housing units across Canada. The results of the field survey components are also discussed qualitatively in a working paper[2)] submitted to CMHC in late June 1982.

The original intention of this component of the project was to attempt to relate moisture induced problems to the age of the unit (based on the hypothesis that the problem was time-related). Since complete files were not available on all the troubled houses, this was difficult to accomplish with any degree of statistical reliability. The field survey data was, therefore, analyzed to identify a number of "causal" factors that could be statistically "linked" to the severity of the problem.

As detailed in this report, siding problems were prevalent in Newfoundland and, to a lesser extent, in the rest of the Atlantic Provinces. On the other hand, wall problems were common in the Maritimes, Quebec and Ontario (but not often mentioned in Newfoundland). Window problems were common in the Prairie Provinces, while roof and ceiling problems were commonly reported in Ontario, the Prairie Provinces and British Columbia.

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1) The analysis of the results of the telephone agency survey are contained in the report entitled "Moisture Induced Problems in NHA Housing Agency Survey Results" CMHC 176-4-25 by Marshall Macklin Monaghan, dated June, 1982.
2) Working Paper Field Survey Results Stream A Part A2(b) - CMHC 176-4-25 by Marshall Macklin Monaghan, dated June, 1982.

Although the comments relate specifically to data received during the agency survey and include an obvious reporting bias, it was generally confirmed in the field survey that moisture induced problems were manifested differently, depending on geographic location and, therefore, meso-climate.

This report, therefore, contains the following:

- Description of the field survey data base,
- Analytical techniques employed,
- Results of the statistical analysis of the field survey results,
- Further analysis of the agency survey information,
- Predictions of the incidence of future moisture related problems in NHA housing.

Future expected incidence of moisture induced problems is based on a further analysis of the agency survey. The field survey was structured to assist in increasing the understanding of the complex relationship between lifestyle and other factors and moisture induced problems in NHA housing.

The report contains a statistical analysis of the field survey to identify the causal factors for the various types of "damage" or potential moisture induced problems.

2.0 FIELD SURVEY DATA BASE

The field survey data file contains 324 variables for 201 NHA problem houses across the country. These variables relate specifically to the two questionnaires (Appendix A) and also include site specific meso-climatic data. Variables collected cover a wide range of topics and can be summarized as follows:

TABLE 2.1

FIELD SURVEY VARIABLE DESCRIPTION[1)]

Variable Number	Questionnaire and Question	General Comments
	Physical Survey	
1 - 6	1.1 - 1.2	House identification
7 - 12	1.3	Weather condition at test time
13 - 18	2.1 - 2.6	General house description
19 - 55	3.1 - 3.7	Description and identification of outside damage.
56 - 117	4.1 - 4.11	Description and identification of first floor damage.
118 - 179	5.1 - 5.11	Description and identification of second floor damage.
180 - 199	6.1 - 6.14	Description and identification of basement damage.
200 - 204	7.1 - 7.4	Description and identification of crawl space damage.
205 - 224	8.1 - 8.7	Description and identification of attic damage.

1) For actual survey instruments, see Appendix A.

TABLE 2.1
(continued)

Variable Number	Questionnaire and Question	General Comments
	Occupant Survey	
225 - 232	1(a) - 1(d)	Description of occupants
233 - 282	2 - 12	Description of heating system humidification and occupant habits regarding heating and venting the house.
283 - 303	13(a) - 13(g)	Observations regarding condensation on windows and walls throughout the house.
304 - 309	14(a) - 15(d)	Observations regarding any retrofit or reinsulation.
310 - 324	-	Specific mesoclimatic information.

The data base was entered on magnetic media for further analysis.[1)]

Because questionnaires were organized to cover a large number of potential observations (not all of which were necessary or possible for every house[2)]), the file was organized so that any particular missing observation could be eliminated from the analysis, should the statistical test so require.

---

1) Analysis was by means of SPSS (Statistical Package for the Social Sciences).

2) As an example, question 3.6 in the physical survey "moisture reading through exterior siding" is not in the data base for brick veneer sided houses.

The data file was further stratified by sub-region to correspond, as far as possible, with the availability of detailed meso-climatic data (see Table 2.2).

TABLE 2.2

GEOGRAPHIC DISTRIBUTION OF HOUSES TESTED

House Code	# Observations	Location
Newfoundland		
101 - 141	41	St. John's/Clarenville
Maritimes		
201 - 215	15	Sydney/Halifax, Nova Scotia
221 - 227	7	Saint John, New Brunswick
231 - 232	2	Moncton, New Brunswick
Quebec		
301 - 313	13	Montreal
321 - 333	13	Quebec City/Chicoutimi
Ontario		
401 - 413	13	Toronto/Oshawa
441 - 449	9	North Bay
481 - 490	10	Sault Ste. Marie
Prairie Provinces		
501 - 511	11	Winnipeg/Eriksdale/Vogar, Manitoba
521 - 536	16	Thompson, Manitoba
British Columbia		
601 - 622	22	B.C. Interior
631 - 647	17	Vancouver Island
648 - 659	12	Prince Rupert
Total	201	

3.0 FIELD SURVEY ANALYSIS

3.1 Principles and Procedures of Inquiry

Notwithstanding original expectations, there is no single specific definition of moisture damage in housing. Problems, as observed and measured, encompasses the following:

- o buckling and warping of siding and other siding problems
- o high moisture readings in sheathing
- o mould and mildew within the houses
- o high moisture readings within the wall system
- o high levels of window condensation and window frame damage
- o mould, mildew and high moisture readings in the attic space

From a structural point of view, only some of the problems present a potential danger. The actual extent of this potential problem is difficult to quantify because of the one time measurement of moisture readings.

The effect of the summer season on drying of the structural members has not been assessed. This aspect will need to be addressed as part of a future ongoing research program.

In interpreting the data, especially that relating to moisture readings in wood products, it should be recognized that all wood products in normal use will contain some moisture. For example, wood kept in a room at 21°C with 30% relative humidity will stabilize at a moisture content of about 5-10%. Under normal conditions, the moisture content within an exterior wall is expected to be in the range of 8 to 15% depending on the location in Canada and the season of the year. Elevated moisture readings are expected from time to time but will only become a problem if the product remains at 22% moisture contents or higher for a prolonged period of time at warm temperatures.

Based on qualitative field observations, ongoing research and the results of the literature review, problems or damage (statistically the dependent variables) are defined as follows:

- o Moisture readings in siding (question 3.6, physical survey)
- o Buckling and warping of siding (question 3.7, physical survey)
- o Paint damage of siding (question 3.7, physical survey)
- o Moisture readings in sheathing (question 3.6, physical survey)
- o Mould and mildew, first floor (question 4.2, physical survey)
- o Mould and mildew, second floor (question 5.2, physical survey)
- o Condensation on windows (question 4.6, physical survey)
- o Moisture readings in exterior walls, first floor (question 4.3, physical survey)
- o Moisture readings in exterior walls, second floor (question 5.3, physical survey)
- o Moisture readings in the attic (question 8.4, physical survey)
- o Mould and mildew in the attic (question 8.7, physical survey)

Independent (causal variables) are discussed in further detail in Section 3.3 but, generally, cover the following parameters:

- Meso-climate
- Occupancy and lifestyle
- Heating/humidification/condensation/ventilation
- House information
- Moisture and humidity readings.

The data matrix contains 65 124 potential cells (201 x 324) covering a large number of potential field observations. Because many of the observations were either not applicable or possible for all housing units, many of the cells contain "zero" readings.

All field observations were taken in NHA housing where moisture problems had been reported. Regression techniques were, therefore, not considered relevant for analytical purposes. A three staged discriminate analysis (partly qualitative and partly statistical) was, therefore, employed.

Stage 1 involved the selection of what are perceived to be the most relevant variables (dependent and independent). Selection was on the basis of field observations, findings from the research and literature components of this project (Part 2) and calculations and conclusions from the Applicable Moisture Reduction Technique component of the project (Part 3).

This initial subjective screening resulted in the identification of some 57 independent variables expected to best explain the presence and level of moisture related problem observed (or measured).

Stage 2 involved the computation of the means and other statistics for each of the 57 independent variables for each "dependent" (problem or damage) variable. The results of this step are detailed in Appendix B. Where the means appeared to be different, the probability of this difference being significant was tested as per the following step.

Stage 3 involved the testing of the level of significance of the difference in the means for each independent variable selected in Step 2.

Because of the relatively small number of observations for high and low problems or damage, it was necessary to use small sampling theory in the statistical test.

It was assumed that the dependent variables came from the same underlying distribution (variances are the same).

The test methodology, therefore, involved a two-tailed null-hypothesis with rejection of H_o (there is essentially no difference between the means) at the 10 percent level of significance. This can be interpreted to mean that there is a 90% or better chance that, given a difference between the two sets of observations, it will be detected by the statistical test technique.

Essentially, the above statistical test permits one to determine if any of the observed factors (lifestyle, weather, size of house, etc.) result in increased moisture related problems (mould and mildew, window condensation, etc.). The results of this analysis are summarized in Section 3.3.

The above method permits the identification of independent variables that cluster for the two extremes (low and high problems or damage).

The equations governing this test of significance are as follows:

Under the hypothesis Ho,

$$t = \frac{x_1 - x_2}{\sigma\sqrt{\frac{1}{N_1} + \frac{1}{N_2}}}$$

where

$$\sigma = \sqrt{\frac{N_1 S_1^2 + N_2 S_2^2}{N_1 + N_2 - 2}}$$

t = the percentile value for the "Student's t Distribution"

$\bar{x}$ = the calculated means for damage levels 1 and 2

N = the number of valid observations for damage levels 1 and 2

S = the standard deviation from the calculated means of observations for damage levels 1 and 2

It can, therefore, be assumed that these significant "independent" variables, either solely or in combination, cause or explain the level of damage observed.

However, because only problem houses were investigated, it is not possible to extrapolate these results directly to non-problem houses.

It is also important to note that the study was done in Canada, on Canadian NHA housing stock. Care should, therefore, be taken in transferring the results of this study to a different situation with, possibly, different weather conditions, building details and occupant lifestyles.

3.2 Field Survey Analysis

As detailed in Section 3.1, 57 independent, or (causal) factors were identified for further analysis as to their effect on the level of "damage or problem" observed or measured. A table detailing the average reading for each of these field observations is included in Appendix B[1)].

---

1) It should be noted that all moisture readings were taken in representative locations. No attempt was made to take readings close to obvious faults in the vapour barrier (electrical outlets).

Levels of "damage or problem" were defined as follows:

i) Siding Problems

Three observations for problems in siding were analyzed.

Moisture Readings In Siding

Where measured readings of 22% moisture content or higher were obtained, this was classified as high. This reading indicates that, under the right environmental conditions[1)], rot could occur. Eleven (11) cases of high readings were observed. This represents 18% of the sample where siding moisture readings were taken. Moisture content readings of 15% or less were classified as "low", since this reading is far removed from the level where rot could occur. Readings of this level were observed in 30 cases (50% of the units where siding observations were possible). The remaining observations were between the two extremes.

Readings were taken in representative locations and averaged for each unit prior to statistical evaluation.

Buckling and Warping of Siding

"Major" buckling and warping of siding was observed in 16 (27.5%) of the cases where this problem was observed. A "major problem" was defined as overall buckling or swelling of siding on more than 50% of any wall. Minor buckling or warping (72.5% of the cases where siding damage was observed) was defined as very localized, covering only a small percentage of any wall.

---

1) Sustained warm conditions at moisture contents of 22% and higher.

Paint Damage to Siding

"Major" paint damage was observed in 8 (21.5%) of the units where this type of damage was apparent. Major damage was defined as missing or damaged paint on any one wall on a total area of 3-4 square feet or more. Minor damage was recorded in 78.5% (29 cases) of the cases where paint damage was noted. "Minor" damage was defined as covering a total area of less than 3 square feet on any one wall.

ii) Sheathing Damage

Moisture Readings in Sheathing

Similar to siding moisture readings, where levels in excess of 22% were recorded, damage was classified as high. This particular condition was observed in 11% (2 cases) of the cases where moisture readings were taken. "Low" readings of 15% or less were observed in 61% (11 cases) of the cases. As with siding observations, readings were average prior to statistical evaluation.

Although these observations have been included in the analysis, it should be noted that with only 18 valid readings, any conclusions must be considered descriptive and not statistically significant.

iii) Level of Mould and Mildew Observed

Mould and mildew observations were made both on the first and second floor of the units investigated.

Mould and Mildew, First Floor

Major mould and mildew was defined as an occurance where growth or staining was observed in large patches on the walls or ceiling, as well as in corners. This classification of damage was observed in 22.5% of the cases (30 cases) where the incidence of mould and mildew was recorded on the first floor.

"Minor" mould and mildew refers to small, localized, patches usually in corners, at the ceiling or floor. This condition was observed in 77.5% of the cases (104 cases) where mould and mildew was found on the first floor.

Mould and Mildew, Second Floor

Definitions of damage levels used are similar to those for the first floor. Major damage was noted in 21.5% of the cases (13 cases) where mould and mildew was observed on the second floor, while minor damage was noted in 78.5% of the cases (48 cases).

iv) Window Condensation

Window condensation was noted as a major problem in 41.5% of the cases (38 cases) where condensation was observed. "Major" was defined as a condition where continual moisture running from the windows was severe enough to cause window frame mould, rot, or other localized water damage in the general area of the window. In many instances condensation resulted in damage to the interior face of the wall (plaster or wallboard damage). With heavy window condensation, it is expected that water will enter the wall system (underneath the window sill) and localized rot or insulation damage is expected to be prevalent.

Minor problems were noted in 54 cases (58.5%) if condensation occured only during short periods of high moisture generation (showers, cooking, etc.).

v) Moisture Readings Exterior Walls

Where possible, an indicative set of moisture readings was taken both on the first and on the second floors.

Moisture Readings, First Floor

As a proxy for conditions inside the wall system, moisture readings were taken in the outside wall studs (but on the inside face). As with other readings of this type, 22% moisture content was defined as "high", since this level approaches the point where, under favourable conditions, damage could occur. High readings were only noted in 3.0% of the cases (4 cases) where observations were possible.

"Low" readings (moisture readings less than 15%) were noted in 75% of the cases (95 cases) where observations were made. Average readings for each unit were evaluated statistically.

Moisture Readings, Second Floor

"High" readings were noted in 13.8% of the cases (8 cases) and "low" readings in 62% of the cases (36 cases). The remaining readings fell between the two extremes. Average readings only were statistically evaluated.

vi) Attic Condition

Where attic access was possible, moisture readings and mould and mildew observations were made.

Moisture Readings, Attic

Attic moisture readings were taken in the structural members and in sheathing. "High" readings (22% moisture content or higher) were found in 13.7% of the cases (6 cases). Fifty-seven percent of the cases (25 cases) showed only minor problems (15% moisture content or less). As with other moisture content readings, the average readings for the unit were evaluated statistically.

Mould and Mildew, Attic

Major mould and mildew, covering more than 50% of the attic sheathing and the roof joists at the contact face with the sheathing was found in 39% of the cases (18 cases) where mould and mildew was observed. Small patches, in localized areas only, were found in the remaining 61% (28 cases).

As described in Section 3.1, a "difference of means" tests was performed, for each level of damage or moisture problem.

The results of these tests indicate clearly the causal factors differentiating housing units with low damage or limited problems from those with high problem levels. It should, be stressed, however, that this test does not differentiate between houses with no problems and problem units. Although some conclusions can be drawn from the data, since there are factors common to both low problem and high problem houses. Given the limitations of the data base , the relevance of these variables cannot be statistically evaluated.

Problem houses investigated were unique in that the following characteristics differentiated them from the general Canadian housing stock[1]:

- Average household size	- 4.1 people
- Exposure to the wind	- higher than average
- Relative humidity, first floor	- 48.6%
- Relative humidity, second floor	- 49.8%
- Average year unit was constructed	- 1975
- % of units with electric baseboard heat	- 81%

This compares to an average 1981 households size of 2.9 for Canada as a whole.[2] Problem units are thus characterized by large household (41% larger). In fact, households of 6 or greater were not uncommon. Relative humidities in problem houses of 49-50% are much higher than what would normally be expected during winter or early spring periods. (A set of lecture notes prepared by N.B. Hutcheson of NRC[3]) indicates a Canadian average indoor relative humidity condition during winter periods (average outdoor temperature of 0°C or lower, of about 35% and less).

Comparable Canadian data on age of housing unit and percent of units with electric baseboard heating is not readily available (the data from the 1981 census were not published when this report was prepared).

---

1) The Contract required the Consultant to investigate only units where problems had been reported.
2) 1981 Census.
3) "Science of Canadian Buildings, Chapter 12 Water and Buildings" by N.B. Hutcheson, NRC, May 1979.

There is, however, little doubt that houses with moisture related problems (major or minor) are significantly newer than the Canadian housing stock in general, and have a much higher incidence of flueless heating types (primarily baseboard electric heating).

3.3 Causal Factors of Moisture Related Problems

The causal factors that showed a statistical difference in mean value for the problem extremes described previously are summarized in the following Figure 3.1.

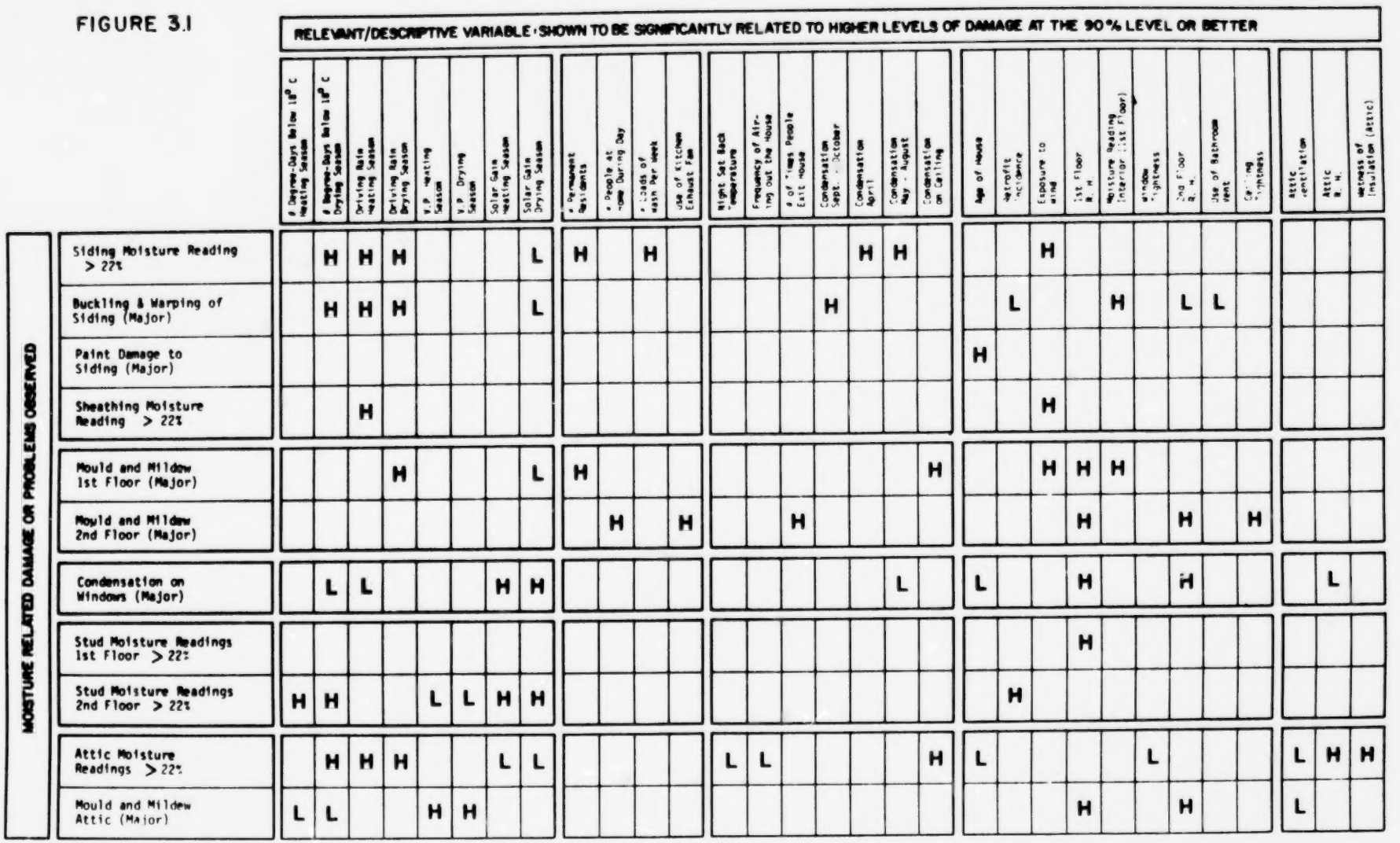
Where an "H" has been entered, the reading for the variable was high in the major problem catagory, while an "L" indicates that lower values of the independent variables tended to result in a major incidence of damage or problems. Both "H" and "L", however, indicate that a statistically significant correlation was observed.

As an example, "high moisture readings in the siding" correlated strongly with a "high number of degree days below 18°C during the drying season (436 vs 343 for low moisture readings)". On the other hand, the same category correlated with low solar gain during the drying season (9 483 vs. 11 205 mega-Joules/m^2). In other words, the location where major damage of this type is likely to occur is relatively cold and has a limited amount of sunshine. All other variables should be interpreted in a similar manner.

3.3.1 - Problems in the Siding and Sheathing Complex

i) High moisture readings in siding, approaching the level where under the proper environmental conditions problems could be expected, are found under the following conditions:

FIGURE 3.1


RELEVANT/DESCRIPTIVE VARIABLE SHOWN TO BE SIGNIFICANTLY RELATED TO HIGHER LEVELS OF DAMAGE AT THE 90% LEVEL OR BETTER
MOISTURE RELATED DAMAGE OR PROBLEMS OBSERVED
Degree-Days Below 18° C Heating Season
Degree-Days Below 18° C Drying Season
Driving Rain Heating Season
Driving Rain Drying Season
V.P. Heating Season
V.P. Drying Season
Solar Gain Heating Season
Solar Gain Drying Season
Permanent Residents
People at Home During Day
Loads of Wash Per Week
Use of Kitchen Exhaust Fan
Night Set Back Temperature
Frequency of Airing Out the House
# of Times People Exit House
Condensation Sept. - October
Condensation April
Condensation May - August
Condensation on Ceiling
Age of House
Retrofit Incidence
Exposure to Wind
1st Floor R. H.
Moisture Reading Interior (1st Floor)
Window Tightness
2nd Floor R. H.
Use of Bathroom Vent
Ceiling Tightness
Attic Ventilation
Attic R. H.
Thickness of Insulation (Attic)
Siding Moisture Reading > 22%
Buckling & Warping of Siding (Major)
Paint Damage to Siding (Major)
Sheathing Moisture Reading > 22%
Mould and Mildew 1st Floor (Major)
Mould and Mildew 2nd Floor (Major)
Condensation on Windows (Major)
Stud Moisture Readings 1st Floor > 22%
Stud Moisture Readings 2nd Floor > 22%
Attic Moisture Readings > 22%
Mould and Mildew Attic (Major)

- Regions where the following weather conditions prevail:
  - colder weather, especially during the drying (spring) season, (April - May);
  - high incidence of driving rain during the winter and spring;
  - low solar gain, particularly during the drying (spring) season;
  - high wind conditions, with the housing unit exposed.
- Households in units where problems can be expected:
  - have a large family size (5.9 was recorded as the average size for high problem units as compared to 4.4 for low problem units) - as a result, household operation related variables, such as loads of washing per week, etc., are also high;
  - also had condensation problems in the spring and summer (although this was not expected to be the cause of high siding moisture readings).

ii) Major buckling and warping of siding was observed under the following conditions:

- Regions with weather conditions very similar to those where high siding moisture readings were recorded:
  - cold weather, especially during the spring;
  - high incidence of driving rain during the winter and spring;
  - low solar gain, especially during the spring period.

- Family lifestyles did not seem to affect the degree of incidence of buckling to any significant extent, except for the following:
  - bathroom vents seemed to be less frequently used.
- Housing units where more severe problems were observed:
  - were less likely to be retrofitted;
  - had greater condensation problems in the fall (September, October);
  - had higher (but still well below the potential problem level) moisture readings in internal structural members. This is an indication that because of lifestyles and weather factors, the houses are generally "wetter" inside;
  - had lower relative humidities on the second floor

iii) Major paint damage to siding was observed primarily in older units. Although there is no statistical support, this seems to indicate that paint damage, where present, is localized in areas where vapour barrier detailing problems exist. (2nd floor header locations).

iv) High moisture readings in sheathing, approaching the level where under proper environmental conditions problems could be expected, were observed in only a very few units. This is supported by the field research (destructive observations) which found high readings only in localized areas where the vapour barrier was penetrated (electrical outlets, etc.). However, where observed, the general pattern of causal factors seems to follow that for other siding problems.

- high driving rain;
- high exposure to the wind.

3.3.2 - Mould and Mildew in the Living Space

i) Major incidence of mould and mildew on the first floor was observed under the following conditions:

- Regions where the following weather conditions prevail:
  - high incidence of driving rain, especially during the spring (drying) season;
  - low solar gain, especially during the drying (spring) season. It should be noted that although solar gain is lower for high incidence of mould and mildew, the absolute solar gain for areas with mould and mildew problems is quite high (significantly higher than that experienced on the east coast maritime areas). It is more representative of that found in all other areas of the country (except the prairie region which has higher solar gain);
  - high wind conditions with houses exposed.

- Families living in houses where problems can be expected:
  - have a larger average family size than units where only limited mould and mildew was noted (4.6 people as compared to 3.9 people for low problem units). As a result of the size of the family and lifestyle, major mould and mildew on the ground floor was associated with high RH levels on the first floor (53.8% RH).

- Houses where major mould and mildew was observed on the ground floor had:
  - significant incidence of condensation, especially on ceilings;

- higher (but still well below the danger point) moisture readings in internal structural members. This is an indication of the relatively high RH levels on the first floor.

ii) Major incidence of mould and mildew on the second floor was observed under the following conditions:

- Houses where families:
  - had 4.8 permanent residents, but more importantly, had 3 people at home during the day as compared to an average of 1.8 at home during the day in low problem units. Elevated RH levels were found on both the ground and second floors (50.8% and 54.5% respectively).
- Houses where major mould and mildew was observed on the second floor:
  - generally had an apparently good ceiling vapour barrier, and attic hatch seals which did not permit moisture to escape into the attic space.

3.3.3 - Condensation on Windows

i) Major incidence of window condensaton was observed under the following conditions:

- Regions where the following weather conditions prevail:
  - warmer weather conditions, especially during the drying season (spring and early summer);
  - high solar gain during both the winter and spring;
  - low incidence of driving rain, especially during the heating season.

The above causal factors should be interpreted with caution in that major problems were observed in two very different weather regimes. In the very cold areas, such as Thompson (high solar gain, low driving rain), condensation damage was caused by frost on windows melting when the sun warmed up the windows during the day. Damage was also observed on the west coast, especially in the Vancouver/Victoria area. Here, single pane windows contributed significantly to the problem.

- Where major window condensation was observed:
  - a low incidence of condensation was reported, especially in the May - August period (it is expected that this is a reflection of the Thompson, Manitoba weather, as well as the generally warm west coast climate);
  - there was a generally low RH in the attic. (Again, this is probably an indication of the very dry Thompson weather, with high solar gain.)

3.3.4 - Exterior Wall Structural Members

i) Although not very common, a few incidences of moisture readings in excess of 22% were observed on the first floor studs.

Based on the very limited data, the only significant correlation found was with ground level interior RH levels.

ii) The incidence of elevated moisture readings in second floor studs was more common than in those on the ground floor. Significant relationships were found under the following conditions:

- Regions where the following weather conditions prevail:
  - colder weather, during both the winter and spring seasons;
  - high solar gain, during both the winter and spring seasons;
  - low vapour pressure, during both the winter and spring seasons.
- Houses where problems were observed:
  - often had insulation added (retrofit), especially in the walls and ceiling.

3.3.5 - Attic Condition

i) Major incidence of mould and mildew in the attic was observed under the following conditions:

- Regions where the following weather conditions prevail:
  - warmer temperatures, during both the winter and spring period;
  - high vapour pressures during both the winter and spring periods.
- Although there was no significant difference shown in family lifestyle, where attic mould and mildew was observed, significantly higher RH levels existed on both the first and the second floors.
- Houses where major mould and mildew was noted in the attic usually had poor attic ventilation with soffit vents covered or missing.

ii) High moisture readings in attic sheathing and structure membranes were observed under the following conditions:

- Regions where the following weather conditions prevail:
  - colder weather, especially during the spring period;
  - high incidence of driving rain, both during the winter and the spring;
  - low solar gain, both during the winter and the spring.
- Although there was no significant difference in family size, the following lifestyle related factors were noted as significant for houses with high moisture readings in attic structural members:
  - low frequency of airing out the house;
  - night time thermostat setback to a lower level.
- Houses, where problems were noted, generally had:
  - higher levels of condensation on the ceilings;
  - higher RH levels in the attic space;
  - observed wet spots in the attic insulation (often from dripping water off the sheathing);
  - poor attic ventilation (soffit vents were often blocked);
  - windows that were not airtight.

3.4 Conclusion

The foregoing leads to some very definite conclusions as to the factors contributing to the severity of moisture related problems in the NHA financed houses investigated:

- Problems in the siding and sheathing complex appear to be related to a climatic condition found primarily in Newfoundland. In this region, poor drying conditions prevail during the spring season; sustained lower temperatures (lower than all of Canada in the drying season except for Northern Manitoba) are common as are a high incidence of driving rain and low solar gain. In other words, the system is continually "stressed" both from the inside (lifestyle) and outside (weather), without the opportunity of drying out (low solar gain).

  The data fails to support the hypothesis that inside (lifestyle related) conditions significantly affect the severity of the observed siding problem. Although statistical indications of inside moisture levels are weak, it must, nevertheless, be recognized that all units inspected had occupant levels and inside Relative Humidity readings well above normal Canadian averages.

- Mould and mildew, whether on the first or second floor appears to be related to high levels of internal moisture generation. Where this moisture comes in contact with a cool wall, condensation can be expected. The fact that problems are observed in areas of high wind exposure is significant in that the cooling effect of the wind, as it blows into the wall cavity or removes the insulating effect of the airfilm, is probably one of the important factors. High incidence of driving rain is also important in that this condition prevents the wall from properly drying out. Although solar gain is shown as statistically significant, it should be recognized that mould and mildew tends to occur near the highest ceiling, in the shaded area under the soffit. Solar gain is, therefore, not a critical factor to this condition. Although the thermal resistance of the outside air film in the soffit area is higher than on lower portions of the wall, it is still low enough so that the thermal resistance of the total wall is not affected significantly.

- Window Condensation was observed in two very different weather regimes. In the very cold areas such as Thompson (high solar gain, low driving rain), damage was caused by frost on the windows melting when the sun warms up the windows during the day. Damage was also observed on the west coast, especially in the Vancouver/Victoria area. Here, single glazing contributed significantly to the problem.

- Potential Exterior Wall Problems appeared to be related to climate, particularly cold weather. The higher incidence of elevated wood moisture readings on the second floor is indicative of the stack effect and exfiltration on the second floor.

- Two different conditions were observed in the attic. The first, mould and mildew growth requires a combination of warm conditions and moisture. A significant correlation between warmer weather is therefore, to be expected. Although high solar gain adds to the warmer conditions in the attic space, it also tends to dry out the area. These two factors probably counteract each other. High vapour pressures associated with generally warmer temperatures resulted in high RH conditions (confirmed by readings in attics with a major incidence of mould and mildew). Moisture required for mould growth is internally generated and, coupled with poor attic ventilation, appears to be a major cause of the problem.

  The second, high moisture readings in attic structural members, is, however, associated with a completely different weather region. Colder weather, low solar gain and driving rain (Newfoundland weather) are all strongly associated with this problem. Generally moist attic conditions are expected in this area with wet insulation being the result of water dripping from the sheathing. As with the mould and mildew problem, this type of problem was found to be associated with poor attic ventilation.

4. ANALYSIS OF AGENCY SURVEY

The detailed results of the agency survey were included in a previous report[1)] . This nationwide survey of reported problem houses generally support the problems observed during our field investigations.

The agency survey report[1)] also contains a projection and the current (1981) incidence of problem houses across the country. A summary of this information is contained in the following Table 4.1.

As detailed in Table 4.2, the majority of the problem houses have been constructed since 1973. Single family units tend to be somewhat older, while mobile or prefabricated units reporting problems are recently constructed.

Table 4.3 indicates that, except for the coastal regions, problems in semi-detached or multiple housing take longer to be reported than in most other housing types. It is, however, reported by CMHC field offices that occupants of single family housing tend to complain about problems more readily.

Although there was a significant amount of multiple problem reporting, the following general trends are evident:

- Siding problems are predominant in Newfoundland and in single family units and apartments in the Maritime Region (Nova Scotia, New Brunswick, Prince Edward Island) - Table 4.4. On the basis of this table, it is estimated that there are currently about 2 800 NHA financed units with siding problems in Canada.

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1) Moisture Induced Problems in NHA Housing Agency Survey Results, June, 1982. Produced by Marshall Macklin Monaghan Limited for CMHC File 176-4-25.

- Interior wall problems (mould and mildew) are found in all areas of the country. There is a low incidence in Newfoundland and a varying incidence elsewhere as shown in Table 4.5. It is projected that there are currently about 3 100 NHA financed units with a reported mould and mildew problem in Canada.

- Roof and ceiling problems (attic mould and mildew, mould and mildew on ceilings, leaking ceilings, etc.) tend to be concentrated from Ontario westward. Based on the information received, it is expected that this problem, often coupled with wall mould and mildew, is present in about 5 400 NHA financed housing units across Canada (Table 4.6).

- Window condensation appears to be concentrated in the central parts of Canada, with a very low reported incidence in Newfoundland. Based on reported problems, it is expected that significant window condensation, often with associated window frame damage and damage to walls in the immediate area of the window, can be expected in about 3 200 NHA financed units across Canada (Table 4.7).

As detailed in Table 4.8, although units are not exclusively heated by electric baseboard (flueless) heating, this type of heating predominates. Field data was further able to expand on this information and it was found that, in the majority of instances where flueless heating was not indicated as the heating method, conversion to airtight wood stoves had taken place, effectively converting a flued heating type to flueless heating.

TABLE 4.1

MOISTURE INDUCED PROBLEMS IN HOUSING
ESTIMATED TOTAL PROBLEMS[1] INCLUDING UNDER REPORTING BY HOUSING TYPE
REGIONAL SUMMARY

House Type	Region						National Total
	Newfoundland	Maritimes	Quebec	Ontario	Prairie Prov.	B.C.	
Single Family	1 153	178	10	225	388	33	1 987
Semi-detached Row, Duplex Triplex	1 660	107	162	593	1 332	1 663	5 517
Mobile, Modular	-	7	-	18	-	108	133
Apartments	40	186	876	1 012	142	367	2 623
TOTAL	2 853	478	1 048	1 848	1 862	2 171	10 260

1) For detail see "Moisture Induced Problems in NHA Housing Agency Survey Results", Marshall Macklin Monaghan Limited, June 1982.

TABLE 4.2

AVERAGE AGE OF NHA FINANCED HOUSES REPORTING PROBLEMS

(Average Year of Construction)

Area	Unit Type			
	Single Family	Semi-Detached & Attached	Mobile/ Prefab	Apartments
Newfoundland	1975	1976	-	1976
Maritimes	1976	1973	1980*	1971**
Quebec	-	1973	-	1973
Ontario	1976	1973**	1977*	1975
Prairies	1976	1971**	-	1973
British Columbia	1978*	1974	1980	1973

* Very weak (limited observations)

** Probably older than indicated (high readings open ended category - 1970 or older)

TABLE 4.3

AVERAGE NUMBER OF YEARS UNTIL PROBLEMS REPORTED
IN NHA FINANCED HOUSES REPORTING PROBLEMS

(Average Years)

Note: 6 or More = 6

Area	Unit Type			
	Single Family	Semi-Detached & Attached	Mobile/ Prefab	Apartments
Newfoundland	3.5	1.2	-	5.0
Maritimes	2.9	5.5**	1.3*	6.0**
Quebec	-	3.1*	-	1.4
Ontario	2.5	5.0**	2.6*	3.1
Prairies	3.2	4.2**	-	3.8
British Columbia	1.8	2.9	2.3	3.9

* Very weak (limited observations)

** Probably older than indicated (high readings open ended category - 6 years or older)

TABLE 4.4

SIDING PROBLEMS REPORTED IN NHA FINANCED HOUSES

(Incidence by Region)

Area	Unit Type			
	Single Family	Semi-Detached & Attached	Mobile/ Prefab	Apartments
Newfoundland	87.7[1)]	87.0	-	100.0
Maritimes	61.2	26.2	-	64.5
Quebec	-	-	-	-
Ontario	4.7	0.3	-	-
Prairies	12.8	-	-	-
British Columbia	-	-	-	-
No. of Units Nationally	1 203	1 475	-	160

1) This should be interpreted to mean that siding moisture problems were reported in 87.7% of the units reporting problems.

TABLE 4.5

INTERIOR WALL PROBLEMS REPORTED IN NHA FINANCED HOUSES

(Incidence by Region)

Area	Unit Type			
	Single Family	Semi-Detached & Attached	Mobile/ Prefab	Apartments
Newfoundland	11.1[1)]	11.4	-	-
Maritimes	29.2	61.7	100	35.5
Quebec	0	63.0	-	41.2
Ontario	67.6	49.4	100	60.2
Prairies	39.5	0.4	-	12.0
British Columbia	39.4	37.0	100	48.0
No. of Units Nationally	498	1 272	133	1 229

1) See Table 4.4 for interpretation.

TABLE 4.6

ROOF/CEILING PROBLEMS REPORTED IN NHA FINANCED HOUSES

(Incidence by Region)

Area	Unit Type			
	Single Family	Semi-Detached & Attached	Mobile/ Prefab	Apartments
Newfoundland	2.0[1)]	12.7	-	-
Maritimes	20.8	38.3	-	-
Quebec	-	38.9	-	100.0
Ontario	53.3	55.6	77.8	73.4
Prairies	38.7	64.5	-	-
British Columbia	45.5	94.6	100.0	62.4
No. of Units Nationally	345	3 077	122	1 848

1) See Table 4.4 for interpretation.

TABLE 4.7

WINDOW PROBLEMS REPORTED IN NHA HOUSES

(Incidence by Region)

Area	Unit Type			
	Single Family	Semi-Detached & Attached	Mobile/ Prefab	Apartments
Newfoundland	4.2[1)]	4.5	-	-
Maritimes	23.6	-	100	35.5
Quebec	-	1.9	-	41.2
Ontario	49.3	26.6	55.6	31.8
Prairies	75.8	97.5	-	88.0
British Columbia	30.3	3.5	100	-
No. of Units Nationally	516	1 658	125	874

1) See Table 4.4 for interpretation.

TABLE 4.8

% OF HOUSES WITH FLUELESS HEATING OF
NHA HOUSES REPORTING PROBLEMS
(Incidence by Region)

Area	Unit Type			
	Single Family	Semi-Detached & Attached	Mobile/ Prefab	Apartments
Newfoundland	76.5[1)]	99.4	-	100.0
Maritimes	58.0	100.0	100	-**
Quebec	-	100.0	-	100.0
Ontario	66.2	50.0	100	84.9
Prairies	66.7	99.0	-	100.0
British Columbia	45.5*	100.0	100	100.0

* Weak data - very limited observations

** No data

1) See Table 4.4 for interpretation.

5. PREDICTED INCIDENCE OF FUTURE PROBLEMS

5.1 General

As detailed in Section 3 of this report, moisture related problems are the result of a complex combination of a large number of variables (with some autocorrelation), most of which are not controllable. The primary uncontrollable factor is the weather regime. Meso-climate appears to determine the severity of the problem and the type of problem that occurs. Other factors, such as family size, building location, etc. are also important but, other than for some overall parameters such as the large household sizes in problem houses, causal relationships were not as strong as those found for the weather data.

Factors such as weather and household size are difficult or impossible to control. Efforts to prevent future problems must, therefore, concentrate on changes to building detail and/or to regulations/specifications related to ventilation rates or other means of dehumidification.

Although some problems seem to be reported rapidly, a review of Tables 4.2 and 4.3 indicates a definite difference in the average age of the "problem" unit and the time it takes for the problem to be reported. Reasons for this time delay vary, but relate primarily to the fact that it takes some time for the problem to become visible, or severe enough to warrant complaint. Also, in some areas problems are reported very rapidly while, in other areas it may take some time before noticed problems are reported.

To provide a "baseline" for estimating the future extent of the problem, it has been assumed that problems will not occur in units that have been constructed since 1981. Although this is not realistic, without being able to predict future construction levels of NHA housing, the projection of problems in housing units not yet constructed becomes purely hypothetical.

Projections of future problems are, therefore, based on the expected time-delay before problems will occur. This should be interpreted as the minimum number of new moisture related problems that will be recorded over the next few years. The type of problem expected by unit type and by Region will be similar to that recorded in Tables 4.4 to 4.7.

5.2 Methodology

The methodology for projecting the approximate effect of the time-delay (in problems becoming apparent and reported) on the future "incidence" of moisture troubled NHA financed units is outlined below:

i) It is assumed that, through policy or other means (changing construction details), units constructed after 1981 will not be affected. Conversely, it is also assumed that changes will not be made to existing units which will materially affect their likelihood of being moisture damaged at sometime in the future.[1)]

ii) It is assumed that the incidence of problems is normally distributed so that, for the purposes of these projections, calculations can be based on averages. Although this is not strictly the case, the accuracy of the base data does not warrant more detailed calculations (for a further discussion of the level of confidence of the Agency Survey data see the report dealing specifically with the Agency Survey Results.[2)]

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1) This assumption implies that the existing problem units (10 260) will remain and the number of new problems will add to this existing base level. The effect of changes or improvements to existing or new units through retrofit or insulation programs will affect the projections but have not been incorporated since their effect is unknown.

2) "Moisture Induced Problems in NHA Housing, Agency Survey Report", Marshall Macklin Monaghan, June, 1982.

iii) The average time before a problem is reported, by unit type and Region, is summarized in Table 4.3, while the average age of units reporting problems is noted in Table 4.2. It has been assumed that the incidence of the problem noted for each year between the average age of the unit and the last year for which complete reporting is expected (1981 less the average length of time before a problem is reported) is stable and indicative of the future total incidence of problems. This computed expected problem level is applied to NHA financed units constructed in subsequent years.

The basis of the projection is the summary of units constructed, by region under the various types of NHA financing. This information is detailed in the following Table 5.1.

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1) Percent of units constructed in that year with a reported problem on file.

2) Expected problems are noted by Region, by unit type and by age of unit in Tables 5.3.3, 5.4.3, 5.5.3, 5.6.3, 5.7.3, and 5.8.3 of the Agency Survey Report and repeated in Appendix C as Tables C1-C6.

TABLE 5.1

NHA FINANCED DWELLING STARTS BY REGION AND NATIONAL TOTAL

1970 - 1981

YEAR	NEWFOUNDLAND				MARITIMES				QUEBEC			
	S.D.[1]	MULTIPLE[2]	APARTMENT	TOTAL	S.D.	MULTIPLE	APARTMENT	TOTAL	S.D.	MULTIPLE	APARTMENT	TOTAL
1970	452	210	172	834	996	546	1 410	3 552	10 456	5 131	13 278	28 865
1971	690	256	227	1 173	2 151	641	1 308	4 100	12 504	2 799	14 719	30 022
1972	631	181	289	1 101	2 170	1 002	1 549	4 721	15 639	2 839	12 444	30 922
1973	363	30	320	713	1 292	1 173	2 164	4 692	11 240	1 350	11 883	24 473
1974	533	454	38	1 025	1 476	589	1 419	3 484	9 179	758	6 204	16 141
1975	680	1 062	494	2 236	2 565	837	1 619	5 021	12 628	808	9 358	22 794
1976	662	683	515	1 860	2 783	437	2 641	5 861	13 068	1 110	16 203	30 381
1977	400	200	960	1 560	1 986	469	3 150	5 605	9 933	974	15 827	26 734
1978	412	242	277	931	1 812	243	1 540	3 595	6 611	1 625	8 087	16 323
1979	218	136	136	490	989	200	1 178	2 367	4 097	1 209	5 766	11 072
1980	213	232	411	856	553	101	780	1 434	2 999	1 098	4 844	8 941
1981	232	378	102	712	410	47	383	840	3 276	1 138	2 763	7 177

For Footnotes See End of Table.

TABLE 5.1

(continued)

NHA FINANCED DWELLING STARTS BY REGION AND NATIONAL TOTAL

1970 - 1981

YEAR	ONTARIO				PRAIRIES[4]				BRITISH COLUMBIA			
	S.D.[1]	MULTIPLE[2]	APARTMENT	TOTAL	S.D.	MULTIPLE	APARTMENT	TOTAL	S.D.	MULTIPLE	APARTMENT	TOTAL
1970	7 222	9 595	29 304	46 121	7 341	4 377	5 613	17 331	2 877	1 217	5 756	9 850
1971	11 702	11 486	31 246	54 434	11 747	5 185	10 464	27 396	3 716	1 642	6 761	12 119
1972	11 716	11 638	33 769	57 123	14 203	3 704	9 544	27 451	3 711	1 820	6 123	11 654
1973	5 965	10 065	32 636	48 666	9 202	1 903	6 466	17 571	2 260	753	2 125	8 444
1974	2 646	3 472	18 414	24 532	4 827	2 207	3 480	10 514	1 684	1 046	2 983	5 713
1975	5 896	10 764	18 162	34 822	5 927	3 519	5 968	15 407	2 422	2 304	3 919	8 645
1976	6 392	18 328	21 193	45 913	6 284	6 446	9 236	21 966	2 991	2 670	6 328	11 989
1977	6 369	16 235	22 807	45 411	5 818	6 971	13 260	26 049	3 166	3 208	8 548	14 922
1978	3 742	10 119	21 993	35 854	4 172	6 030	11 304	21 506	2 428	2 147	4 230	8 805
1979	2 758	4 680	10 171	17 609	2 386	2 092	7 077	11 555	867	542	4 201	5 610
1980	1 175	2 537	8 200	11 912	1 738	1 050	2 800	5 588	959	943	2 008	3 910
1981	1 060	2 483	7 762	11 305	1 152	757	2 995	5 274	607	1 113	1 509	3 229

For Footnotes See End of Table.

TABLE 5.1

(continued)

NHA FINANCED DWELLING STARTS BY REGION AND NATIONAL TOTAL

1970 - 1981

YEAR	TOTAL			
	S.D.[1]	MULTIPLE[2]	APARTMENT	TOTAL
1970	29 871	24 749	55 533	106 533
1971	42 510	22 009	64 725	129 244
1972	48 070	21 184	63 718	132 972
1973	30 322	15 274	58 900	104 496
1974	20 345	8 526	32 538	61 409
1975	30 118	19 294	39 520	88 932
1976	32 180	29 674	56 116	117 970
1977	27 672	28 057	64 552	120 281
1978	19 177	20 406	47 431	87 014
1979	11 315	8 859	28 529	48 703
1980	7 637	5 961	19 043	32 641
1981	7 107	5 916	15 514	28 537

Footnotes to Table 5.1

1) Single Detached
2) Semi-detached, Town House, Row House, Duplex
3) Prince Edward Island, New Brunswick, Nova Scotia
4) Manitoba, Saskatchewan, Alberta

The aforementioned analysis results in an expected incidence of problems by unit type and by region, as detailed in the following Table 5.2.

Table 5.3 details the results of the above calculations and summarizes the number of additional moisture induced problems in each year (starting in 1982) that are not yet on file but are expected as a result of the time-delay between the completion of the unit and the date of a complaint being recorded.

5.3 Anticipated Total Incidence of Moisture Induced Problems in NHA Housing

Future moisture induced problems will, therefore, be a function of the following:

i) problems currently on file;

ii) problems not yet recorded, but relating to housing units constructed over the last few years;

iii) problems "built into" units constructed from 1982 onwards, if no corrective action is taken to prevent the problem in the future.

Table 5.4 summarizes anticipated future problems across Canada, as a result of the first two factors only.

TABLE 5.2

INCIDENCE OF MOISTURE INDUCED PROBLEMS EXPECTED BY REGION AND UNIT TYPE

	NEWFOUNDLAND			MARITIMES[6]			QUEBEC		
	S.D.[4]	MULTIPLE[5]	APARTMENT	S.D.	MULTIPLE	APARTMENT	S.D.	MULTIPLE	APARTMENT
Average Age of Troubled Units on File[1]	1975	1976	1976	1976	1973	1971	-	1973	1973
Expected Total Annual Incidence[2]	31.1%	28.9%	7.8%	1.2%	2.2%	0.7%	-	1.5%	0.7%
For Units Constructed Since[3]	1979	1981	1977	1979	1977	1976	-	1979	1981

For Footnotes See End of Table.

TABLE 5.2

INCIDENCE OF MOISTURE INDUCED PROBLEMS EXPECTED BY REGION AND UNIT TYPE

(Continued)

	ONTARIO			PRAIRIES[7]			BRITISH COLUMBIA		
	S.D.[4]	MULTIPLE[5]	APARTMENT	S.D.	MULTIPLE	APARTMENT	S.D.	MULTIPLE	APARTMENT
Average Age of Troubled Units on File[1]	1976	1973	1975	1976	1971	1973	1978	1974	1973
Expected Total Annual Incidence[2]	0.5%	0.6%	0.6%	0.4%	2.0%	0.3%	0.2%	8.8%	1.3%
For Units Constructed Since[3]	1980	1977	1979	1979	1978	1978	1980	1979	1978

Footnotes for Table 5.2

1) From Table 4.2
2) Average computed as noted in text
3) First year for which not all potentially troubled units are expected to be on file
4) Single Detached
5) Semi-detached, Town House, Row House, Duplex
6) Prince Edward Island, New Brunswick, Nova Scotia
7) Manitoba, Saskatchewan, Alberta
- No data

TABLE 5.3

ADDITIONAL MOISTURE INDUCED PROBLEMS PROJECTED TO BE RECORDED
FOR UNITS CURRENTLY "IN-PLACE"

Note: This Table takes into account the time-delay between construction and the problem being reported.

	NEWFOUNDLAND				MARTIMES[3]				QUEBEC			
YEAR	S.D.[1]	MULTIPLE[2]	APARTMENT	TOTAL	S.D.	MULTIPLE	APARTMENT	TOTAL	S.D.	MULTIPLE	APARTMENT	TOTAL
1982	0	109	75	184	0	10	18	28	**	18	19	37
1983	31	*	22	53	3	5	22	30	**	16	*	16
1984	77	*	11	88	0	4	8	12	**	17	*	17
1985	*	*	32	32	*	2	8	10	**	*	*	*
1986	*	*	8	8	*	1	5	6	**	*	*	*

For Footnotes See End of Table.

TABLE 5.3

(continued)

ADDITIONAL MOISTURE INDUCED PROBLEMS PROJECTED TO BE RECORDED

FOR UNITS CURRENTLY "IN-PLACE"

YEAR	ONTARIO				PRAIRIES[4]				BRITISH COLUMBIA			
	S.D.[1]	MULTIPLE[2]	APARTMENT	TOTAL	S.D.	MULTIPLE	APARTMENT	TOTAL	S.D.	MULTIPLE	APARTMENT	TOTAL
1982	0	72	59	131	0	121	34	155	0	48	41	89
1983	0	28	49	77	7	42	21	70	0	83	41	124
1984	*	0	47	47	1	21	0	22	*	98	12	110
1985	*	0	*	0	*	15	9	24	*	*	0	0
1986	*	15	*	15	*	*	*	*	*	*	*	*

For Footnotes See End of Table.

TABLE 5.3

(continued)

ADDITIONAL MOISTURE INDUCED PROBLEMS PROJECTED TO BE RECORDED

FOR UNITS CURRENTLY "IN-PLACE"

YEAR	TOTAL			
	S.D.[1]	MULTIPLE[2]	APARTMENT	TOTAL
1982	0	378	246	624
1983	41	174	155	370
1984	78	140	78	296
1985	*	17	49	66
1986	*	16	13	29

Footnotes for Table 5.3

1) Single Detached

2) Semi-detached, Town House, Row House, Duplex

3) Prince Edward Island, New Brunswick, Nova Scotia

4) Manitoba, Saskatchewan, Alberta

* Units currently constructed will not likely result in problems not yet recorded this far in the future.

** Insufficient data on file for projections.

TABLE 5.4

TOTAL MOISTURE INDUCED PROBLEMS IN NHA HOUSING[1)]
PROJECTION PROBLEMS BY REGION FOR HOUSING UNITS "IN PLACE" AS OF 1981

YEAR	NEWFOUNDLAND	MARITIMES	QUEBEC	ONTARIO	PRAIRIES	BRTITISH COLUMBIA	TOTAL
1981[2)]	2 853	478	1 048	1 848	1 862	2 171	10 260
1982[3)]	3 037	506	1 085	1 979	2 017	2 260	10 884
1983[3)]	3 090	536	1 101	2 056	2 087	2 384	11 254
1984[3)]	3 178	548	1 118	2 103	2 109	2 494	11 550
1985[3)]	3 210	558	1 118	2 103	2 133	2 494	11 616
1986[3)]	3 218	564	1 118	2 118	2 133	2 494	11 645

1) Note: This assumes that no corrective action is taken on existing problem units.
2) From Table 4.1.
3) Additional units from Table 5.3.

Future problems anticipated in housing constructed during 1982 and the following years is very much a function of the type of unit constructed. However, since meso-climate is also an important determinant (see Section 3.3), housing location is critical in determining the extent and location of the problem. If it is assumed that future NHA financed units are distributed by unit type and geographic location similar to the 1981 distribution, 1.6 percent of all these units will exhibit a moisture related problem at some later date. (The time-delay being a function of unit type and geographic location).

Table 5.5 details the projected incidence and geographic distribution of problem units for an assumed construction level (NHA financed units only) comparable to 1981 (28 500 units) and for a level approximately equal to the average NHA involvement between 1970 and 1981 (88 000 units). In this case, because of different geographic concentration of units, the total Canadian expect incidence level of moisture problems in newly constructed units drops to 1.4 percent.

If no changes are made in construction details and practices, on a Canada-wide basis, this represents an average from about 460 to 1 220 new problem units each year. Problems will appear from 1 to 5 years after construction is completed.

It should be noted that the projections assume that changes will not be made to the existing housing stock. Nevertheless, conversion programs to flueless heating and tightening of housing units will reduce ventilation rates, and thus, likely increase the incidence of moisture related problems in housing units. As a result, the projections should be considered as baseline data only.

TABLE 5.5

EXPECTED INCIDENCE OF ANNUAL FUTURE
MOISTURE RELATED PROBLEMS IN NEWLY CONSTRUCTED NHA UNITS[1)]

	NEWFOUNDLAND	MARITIMES	QUEBEC	ONTARIO	PRAIRIES	BRITISH COLUMBIA	TOTAL
Percent of Present Units Expected to be Troubled[2)]	30.9%	1.7%	0.7%	0.8%	1.6%	3.5%	1.7%
Additional Troubled Units @ 1981 Contruction Levels (28 500)	193	8	36	68	32	119	460
Additional Troubled Units @ Average Construction Levels 1970 - 1981 (88 000)	434	38	106	216	104	323	1 220

1) Assuming a unit type distribution similar to that of 1981 but with a regional distribution of starts as per 1981 in the first instance and the average of 1970-1981 in the second case.

2) Those constructed from 1973 to 1981 inclusive including an estimate for problems not yet noticed and reported - See Table 5.4.

APPENDIX A

Appendix A contains copies of the Survey Instrument used during the field survey.

[ ] 1-3

OCCUPANT QUESTIONNAIRE

SECTION 1

OCCUPANCY

PLEASE WRITE IN APPROPRIATE CODE

1 (a) Number of permanent residents:

(1) 1 (2) 2 (3) 3 (4) 4 (5) 5 (6) 6
(7) 7 (8) 8 (9) 9 (0) More than 9 [ ] 4

(b) Number of people at home during the day:

SEE CODE FOR QUESTION 1(a) [ ] 5

(c) Number of permanent residents by age:

SEE CODE FOR QUESTION 1(a)

(i) Under 3 years of age [ ] 6

(ii) 3 - 10 years of age [ ] 7

(iii) over 10 years of age [ ] 8

(d) Number of pets kept inside the house

SEE CODE FOR QUESTION 1(a)

(i) fish tanks [ ] 9

(ii) dogs [ ] 10

(iii) cats [ ] 11

SECTION 2

HOUSE PLANTS (If respondent has no house plants, please go to SECTION 3)

2 (a) Number of house plants (by pot diameter):

1" - 4" [ ] 12

5" - 10" [ ] 13

11" - 16" [ ] 14

Over 16" [ ] 15

(b) Number of unglazed clay pots used (by pot diameter):

1" - 4" [ ] 16

5" - 10" [ ] 17

11" - 16" [ ] 18

Over 16" [ ] 19

(c) How often do you spray or mist your plants during the winter months?

(1) Never (2) Once a day (3) Every second day
(4) Once a week (5) Less than once a week [ ] 20

SECTION 3

WASHING

3 (a) Do you have a clothes washing machine?

(1) Yes (2) No [ ]21

(b) If yes, how many loads per week do you wash?

(1) 1 (2) 2 (3) 3 (4) 4 (5) 5 (6) 6
(7) 7 (8) 8 (9) 9 (0) More than 9 [ ]22

(c) What kind of clothes washing machine do you have?

(1) Wringer (2) Automatic (3) Other [ ]23

(d) Do you use a clothes dryer?

(1) Yes (2) No [ ]24

(e) If yes, is it vented to the outside of your home?

(1) Yes (2) No [ ]25

(f) Do you hang clothes to dry inside on wash days?

(1) Yes (2) No [ ]26

4 (a) Could you please estimate the total number of showers taken each week for the entire household?

(1) 0 - 7 (2) 8 - 14 (3) 15 - 21 (4) 22 - 28
(5) 29 - 35 (6) 36 or more [ ]27

(b) Similarly, could you estimate the total number of baths run per week? (for the entire household)

(1) 0 - 7 (2) 8 - 14 (3) 15 - 21 (4) 22 - 28
(5) 29 - 35 (6) 36 or more [ ]28

(INTERVIEWER: Note: Determine the number of tubs of water)

(c) Do you leave water in the bathtub or do you drain the tub immediately?

(1) Always drain immediately
(2) Sometimes leave water in tub
(3) Always leave water in tub [ ]29
(4) Don't know

SECTION 4

COOKING AND CLEANING

5 (a) Do you do most of your cooking on the top of the stove?

(1) Yes (2) No (3) Don't Know [ ]30

(b) Do you have an externally vented fan in the kitchen?

(1) Yes (2) No (3) Don't Know [ ]31

(c) If yes, do you use the kitchen exhaust fan when cooking?

(1) Yes (2) No (3) Sometimes [ ]32

(d) How often do you boil water in a kettle?

(1) Once a day (2) Twice a day (3) three times a day (4) Four times (5) Five times (6) Six times (7) Seven times (8) Eight times (9) Less than once a day (0) Not at all [ ]33

6 (a) Do you use an automatic dishwasher to clean your dishes or do you wash the dishes by hand?

(1) Automatic dishwasher Go to Q. 6b
(2) Do dishes by hand Go to Q. 6c [ ]34

(b) How often are dishes washed using an automatic dishwasher?

(1) Every second day (2) Once a day (3) Twice a day (4) Three times a day (5) More than three times a day GO TO QUESTION 7 [ ]35

(c) When (if) you do the dishes by hand, how many times per day would you wash the dishes?

(1) Less than once a day (2) Twice a day
(3) Three times a day (4) Four times a day
(5) Five or more times a day [ ]36

7 How often do you wash kitchen and bathroom floors?

(1) Twice a week or more (2) Once a week
(3) Every second week (4) Less than every second week [ ]37

SECTION 5

HEATING AND HUMIDITY

8 (a) Please indicate your normal thermostat setting?

(1) During the day _____°F _____°C [ ] [ ] 38/39

(2) During the night _____°F _____°C [ ] [ ] 40/41

(INTERVIEWER: Please code degrees in centigrade)

(b) How often do you turn your thermostat down at night?

(1) Always (2) Usually (3) Sometimes
(4) Infrequently (5) Never [ ]42

(c) If you turn down the thermostat at night, for how long a period?

(1) Less than 4 hours (2) 4 - 5 hours
(3) 6 - 7 hours (4) 8 - 9 hours
(5) 10 - 11 hours (6) 12 hours or more [ ]43

9 (a) Do you use a furnace humidifier during the winter months?

(1) Yes (2) No (3) Don't know [ ]44

(b) Do you use a room humidifier or vaporizer during the winter months?

(1) Yes (2) No (3) Don't know [ ]45

(c) If you do use a humidifer/vaporizer, how often and in which rooms do you use it?

(1) Always (2) Frequently (3) Sometimes
(4) Infrequently (5) Never

i	Living Room	How often?(SEE CODES ABOVE)	[ ]46
ii	Dining Room	How often?(SEE CODES ABOVE)	[ ]47
iii	Bedroom 1	How often?(SEE CODES ABOVE)	[ ]48
	Bedroom 2	" "	[ ]49
	Bedroom 3	" "	[ ]50
	Bedroom 4	" "	[ ]51
	Bedroom 5	" "	[ ]52
iv	Basement	" "	[ ]53
v	Bathroom 1	" "	[ ]54
	Bathroom 2	" "	[ ]55
	Bathroom 3	" "	[ ]56

(d) Please indicate the size of vaporizer/humidifier?

(1) Small (2) Medium (3) Large [ ]57

10 (a) Do you use a dehumidifier in your home during the winter months?

(1) Yes (2) No (3) Don't know [ ]58

(b) Do you use a dehumidifier during the non-winter months?

(1) Yes (2) No (3) Don't know [ ]59

(c) Do you experience shocks (from static electricity) when touching items in your home during the winter months?

(1) Frequently (2) Sometimes (3) None [ ]60

11 (a) Do you "air out" the house regularly (by opening doors and windows) during the winter months?

(1) Yes (2) No [ ]61

(b) If yes, how often?

(1) Once a day (2) Twice a day (3) Twice a week (4) Three times a week (5) Once a week (6) Less frequently (7) Never [ ]62

12 How many times a day (total for the household) do people/pets enter and exit the house?

(1) Less than six per day (2) Six to thirteen per day (3) Thirteen to twenty (4) More than twenty (5) Don't know [ ]63

SECTION 6

CONDENSATION

Condensation is the formation of moisture that occurs when air containing water vapor contacts a cold surface. It will often occur on window panes on very cold days. Condensation will also occur on warmer days when there is a lot of moisture in the air (such as after a hot shower). It may also show up on walls and ceilings in the form of frost or as mildew or water marks.

13 (a) Please indicate for each of the following months how often you notice condensation (or other forms of moisture problems) in your home?

(1) Always (2) Sometimes (3) Never

i	September-October	How often?(SEE CODES ABOVE)	[ ]64
ii	November	" "	[ ]65
iii	December	" "	[ ]66
iv	January	" "	[ ]67
v	February	" "	[ ]68
vi	March	" "	[ ]69
vii	April	" "	[ ]70
viii	May-August	" "	[ ]71

(b) At what times does the condensation occur?

(1) During the day and night (2) At night only (3) During the day only [ ]72

(c) If condensation occurs on windows on what surface does it form?

(1) Inside surface, inside pane (2) Inside surface, outside pane (3) Both (4) Other (5) Don't know [ ]73

(d) Does condensation occur on the window frame?

(1) Yes (2) No (3) Don't know [ ]74

(e) Does condensation occur on the walls?

(1) Yes (2) No (3) Don't know [ ]75

(f) Does condensation occur on the ceilings?

(1) Yes (2) No (3) Don't know [ ]76

(g) Could you please tell me if you have had condensation or moisture problems in any of the following areas in your home? (INTERVIEWER Code Yes (1) No (0))

(1)	Living room walls or ceiling	(1) Yes (0) No	[ ]77
(2)	Dining room walls or ceiling	" "	[ ]78
(3)	Bathroom walls or ceiling	" "	[ ]79
(4)	Master bedroom walls or ceiling	" "	[ ]80
(5)	Other bedroom walls or ceiling	" "	[ ]81
(6)	Basement walls, floors or ceiling	" "	[ ]82
(7)	Exterior closets	" "	[ ]83
(8)	Others, Please specify _____	" "	[ ]84

SECTION 7

14 (a) Do you know when your house was constructed?
INTERVIEWER: Enter last two digits [ ] [ ]$_{85}$ $_{86}$

15 (a) Was your house retro-fitted with additional insulation?

(1) Yes (2) No [ ]$_{87}$

(b) When was the retro-fit done?
INTERVIEWER: Enter last two digits [ ] [ ]$_{88}$ $_{89}$

(c) Where was the insulation added?

(1) Attic (2) Walls (3) Both [ ]$_{90}$

(d) What type of insultation was used?

(1) Don't know (2) No Insulation (3) Batts
(4) Rigid (5) Foam (6) Batts & Rigid (7) Other

(1) Attic (SEE CODES ABOVE) [ ]$_{91}$
(2) Walls (SEE CODES ABOVE) [ ]$_{92}$

PHYSICAL SURVEY [ ][ ][ ] 1/3

1. GENERAL

1.1 Address .....

Province..... [.]4/5

City..... [.]6/7

Street Number..... [. .]8/10

1.2 Date

Day..... [.]11/12

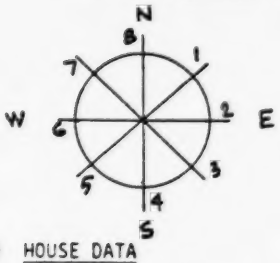
Month..... [.]13/14

1.3 Weather Conditions

Sunny (1) Cloudy (2) Rain (3) Snow (4) [ ]15

Was there prolonged rain in last 24 hours? Yes (1) [ ]16

Dry Bulb _____ °F Wet Bulb _____ °F Relative Humidity [.]17/18



Wind velocity (MPH) [.]19/20

Wind direction (see code) [ ]21

Prevailing wind direction [ ]22

2.0 HOUSE DATA

2.1 Front Face of Unit is facing [ ]23

2.2 Single Storey (1) Two Storey (2) Split Level (3) [ ]24

2.3 Single (1) Semi-Detached (2) Row Housing (3) [ ]25

Apartment (4) Mobile (5) Other (6)

Comments:

2.4 Year of Construction [.]26/27

2.5 Dimensions of living space:

	L	W	Area
Basement	_____	_____	_____
1st Floor	_____	_____	_____
2nd Floor	_____	_____	_____

Total area of living space in 100's of ft² [ ] 28/29

2.6 Shielding factor for house

Very shielded (1) Average (2) Exposed (3) [ ]30

3. EXTERIOR

3.1 Wall Finish

Metal Siding (1) Wood Siding (2) Partical Board (3)
Brick Facing (4) Stucco (5) Others (6)

	F	L	R	B	
First Floor	[ ]	[ ]	[ ]	[ ]	31/34
Second Floor	[ ]	[ ]	[ ]	[ ]	35/38

. Comments: (Manufacturer's name etc.)

3.2 Roof

Flat (1) Sloped < 2:1 (2) Sloped > 2:1 (3) [ ]39

3.3 Roof Materials

Felt & Gravel (1) Asphalt Shingles (2) Metal (3) [ ]40
Others (4)
Comments:

3.4 Vents and chimneys (excluding attic vents). No undampered vents and less than 3 dampered vents (1) [ ]41
3 or more dampered vents or less than 3 undampered vents (2)
3 or more undampered vents (3)

3.5 Eaves and Downpipes. Are they installed? [ ]42
Yes (1) No (2)

3.6 Moisture readings through exterior siding %

	F		L		R		B		
	L	R	L	R	L	R	L	R	
Siding	[.]	[.]	[.]	[.]	[.]	[.]	[.]	[.]	]43/58
Sheathing	[.]	[.]	[.]	[.]	[.]	[.]	[.]	[.]	]59/74
Stud	[.]	[.]	[.]	[.]	[.]	[.]	[.]	[.]	]75/90

3.7 Indication of moisture damage

Minor localized peeling of paint (1)
Major overall peeling of paint (2)
Minor localized buckling or swelling of siding (3)
Major overall buckling or swelling of siding (4)
Others (5) [ ]91

Comments:

4. GROUND FLOOR INTERIOR

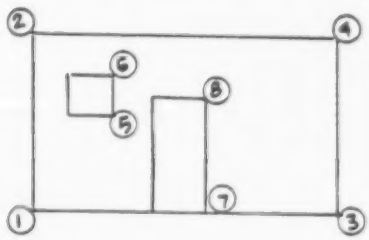
4.1 Dry Bulb _____ °F Wet Blub _____ °F R.H. [.]92/93

4.2 Minor mildew in corners, (1)
Major mildew occurring in patches on walls or celing as well as corners, (2)

F	L	R	B	Ceiling	
[ ]	[ ]	[ ]	[ ]	[ ]	94/98

Comments:

4.3 Moisture Reading in Walls
Location Code [ ][.]Reading



F	L	R	B	
[ ][.]	[ ][.]	[ ][.]	[ ][.]	99/110
[ ][.]	[ ][.]	[ ][.]	[ ][.]	111/122
[ ][.]	[ ][.]	[ ][.]	[ ][.]	123/134

Interior Control Reading (Stud or Stairs) [.]135/136

Comments:

4.4 If house is retrofit, was vapour barrier installed? [ ]137
Yes (1) No (2) Don't know (3)

4.5 Insulation
No Insulation (1) Batts (2) Rigid (3) Blown (5)
Batts & Rigid (6) Other (7) [ ]138

Comments:

4.6 Windows

Type: Double (1) Double Fixed (2) Sealed (3)
Combination of Sealed & Double (4)

	F	L	R	B	
How many?	[ ]	[ ]	[ ]	[ ]	139/142
Type?	[ ]	[ ]	[ ]	[ ]	143/146

Condensation Evidence
Minor (1) Major (2)

	F	L	R	B	
	[ ]	[ ]	[ ]	[ ]	147/150

4.7 Doors

Type: Metal or Wood (1) Glass Patio (2)
Metal or wood with storm (3)

	F	L	R	B	
How many?	[ ]	[ ]	[ ]	[ ]	151/154
Type	[ ]	[ ]	[ ]	[ ]	155/158

4.8 Ventilation Ducts (from house out) Yes (1) No (2)

Range Exhaust Duct	[ ]159
Bathroom Exhaust Duct	[ ]160
Fireplace	[ ]161
Wood Stove	[ ]162

4.9 Fireplace and Wood Stove

Good (1) Average (2) Poor (3) [ ]163

Good: No fireplace or tightly sealed wood stove or fireplace with glass doors & well fitting damper.

Average: Fireplace with either well fitting damper or glass doors or poorly sealed wood stove.

Poor: Both a wood stove & fireplace or a poorly fitted fireplace.

4.10 Wall Tightness

Good (1) Average (2) Poor (3) [ ]164

Good: No cracks and electrical outlets are sealed by gaskets
Average: No gaskets, minor cracks
Poor: Many cracks, no seals, wall penetration

4.11 Window and door tightness and fitting

Good (1) Average (2) Poor (3) [ ]165

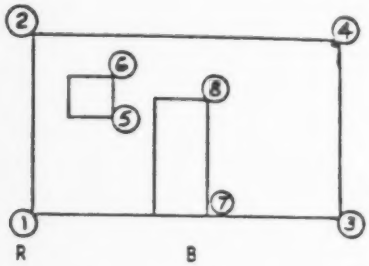
5.0 SECOND FLOOR INTERIOR

5.1 Dry Bulb ____ °F Wet Blub ____ °F R.H. [ ]166/16

5.2 Minor mildew in corners, (1)
Major mildew occurring in patches on walls or celing as well as corners, (2)

F	L	R	B	Ceiling	
[ ]	[ ]	[ ]	[ ]	[ ]	168/172

Comments:



5.3 Moisture Reading in Walls
Location Code [ ][.]Reading

F	L	R	B	
[ ][.]	[ ][.]	[ ][.]	[ ][.]	173/184
[ ][.]	[ ][.]	[ ][.]	[ ][.]	185/196
[ ][.]	[ ][.]	[ ][.]	[ ][.]	197/208

Interior Control Reading (Stud or Stairs) [.] 209/210

Comments:

5.4 If house is retrofit, was vapour barrier installed? [ ]211
Yes (1) No (2) Don't know (3)

5.5 Insulation
No Insulation (1) Batts (2) Rigid (3) Blown (5)
Batts & Rigid (6) Other (7) [ ]212

Comments:

5.6 Windows
Type: Double (1) Double Fixed (2) Sealed (3)
Combination of Sealed & Double (4)

	F	L	R	B	
How many?	[ ]	[ ]	[ ]	[ ]	213/216
Type?	[ ]	[ ]	[ ]	[ ]	217/220

Condensation Evidence
Minor (1) Major (2)

F	L	R	B	
[ ]	[ ]	[ ]	[ ]	221/224

5.7 Doors

Type: Metal or Wood (1) Glass Patio (2)

Metal or wood with storm (3)

	F	L	R	B	
How many?	[ ]	[ ]	[ ]	[ ]	225/228
Type	[ ]	[ ]	[ ]	[ ]	229/232

5.8 Ventilation Ducts (from house out) Yes (1) No (2)

Range Exhaust Duct	[ ] 233
Bathroom Exhaust Duct	[ ] 234
Fireplace	[ ] 235
Wood Stove	[ ] 236

5.9 Fireplace and Wood Stove [ ] 237

Good: (1) No fireplace or tightly sealed wood stove or fireplace with glass doors & well fitting damper.

Average: (2) Fireplace with either well fitting damper or glass doors or poorly sealed wood stove.

Poor: (3) Both a wood stove & fireplace or a poorly fitted fireplace.

5.10 Wall Tightness [ ] 238

Good (1) Average (2) Poor (3)

Good: No cracks and electrical outlets are sealed by gaskets

Average: No gaskets, minor cracks

Poor: Many cracks, no seals, wall penetration

5.11 Window and door tightness and fitting [ ] 239

Good (1) Average (2) Poor (3)

6. BASEMENT

6.1 Perimeter Walls [ ] 240

Concrete (1) Masonry (2) Timber (3)

6.2 Finish [ ] 241

Unfinished (1) Partly Finished (2)

Fully finished including ceiling (4)

6.3 Insulation in Walls [ ] 242

Yes (1) Don't know (2)

6.4 Vapour Barrier [ ] 243

Yes (1) Don't know (2)

If yes, is it installed around headers [ ] 244

Yes (1) Don't know (2)

Is it installed on warm side of insulation [ ] 245

Yes (1) Don't know (2)

6.6 Is there open sump [ ]246
Enter (1) if Yes

6.7 Air Humidity Wet Blub ____ °F Dry Bulb ____ °F
Relative Humidity [ ]247/248

6.8 Moisture Readings

	F	L	R	B	Joist	
In Headers	[.]	[.]	[.]	[.]	[.]	249/258

6.9 Visible Leakage
Minor (Damp to wet) (1) Visible Leak (2) [ ]259
Major (3)

6.10 Laundry Lines
Yes (1) Drying Laundry on Lines (2) [ ]260

6.11 Furnace
Oil (1) Gas (2) Electric (3) Wood (4) [ ]261
Is humidification attached: Yes (1) [ ]262

6.12 Heating System
Force Air (1) Hot Water (2) [ ]263
Electrical Baseboard heaters (3)
Combination of 1 or 2 with electrical baseboard heaters (4)
Others (5)

6.13 Heating System rating
Good (1) Average (2) Poor (3) [ ]264

Good: Completely Electric
Average: Fossil Fuel Fired
Poor: Fossil Fuel, No dampers

6.14 Ductwork
Good (1) Average (2) Poor (3) [ ]265

Good: No ductwork, No floor penetration through ext. wall (1)

Average: Ductwork inside of house and only few (less than 3) penetration through exterior walls (2)

Poor: Ductwork through exterior walls and many penetrations through ext. walls (3)

7. CRAWL SPACE

Enter (1) If there is crawl space
(2) if it was not investigated [ ]266

7.1 Ventilation Good (1) Poor (2) [ ]267

Comments:

7.2 Air Humidity
Wet Bulb ____ °F Dry Bulb ____ °F Relative Humidity [.]268/269

7.3 Vapour Barrier Yes (1) Don't know (2) [ ]270

7.4 Any deterioration Fungi (1) Moisture Damage (2) [ ]271

Comments:

8. ATTIC

Yes (1) but if it was not investigated enter (2) [ ]272

8.1 Insulation

Batts (1) Blown Fibreglass (2) Blown Cellulose (3)
Rigid (4) Others (5) [ ]273

How thick? (Enter thickness in inches) [ ]274
Is it dry (1) moist (2) wet (3) [ ]275
If wet, are these only local spots ? Yes (1) [ ]276

Comments:

8.2 Vapour Barrier: Ripped or damaged Yes (1) [ ]277
Not covering over partition walls (1) [ ]278
Is access hatch seal good (1) Poor (2) [ ]279

8.3 Air humidity wet bulb ____ °F dry bulb ____ °F [.]280/281
Relative Humidity

8.4 Moisture Reading

Sheathing	Top Chord	Diagonal	Bottom Chord	
[.]	[.]	[.]	[.]	282/289

8.5 Ventilation of Attic

No. of attic vents through roof (enter number) [ ]290

Soffit vents: free for air movement (1) [ ]291
covered with insulation (2)

Are there any vents from house terminating in attic space [ ]292
(Enter Number)

8.6 Tightness of ceiling below attic

Good (1) Average (2) Poor (3) [ ]293

Good: No cracks or holes all vents well sealed
Average: Some cracks, some holes around ducts
Poor: Cracks, holes around ducks, hatch poorly sealed
vapour barrier is not over partitions

8.7 Roof Moisture Observation

Is there mold growth on sheathing and trusses [ ] 294
Minor (1) Major (2)

If yes, what colour white (1) gray (2) [ ] 295
black (3) brown (4)

Was sample taken Yes (1) [ ] 296

Comments:

9. INTERIOR WALL COVERING

9.1 Type of paint on jamority of outside walls
Gloss (1)
Semi-Gloss (2)
Flat (3) [ ] 297

9.2 Type of paint on majority of inside walls
Gloss (1)
Semi-Gloss (2)
Flat (3) [ ] 298

APPENDIX B

COMPARISON OF MEANS

BY

TYPE OF DAMAGE

NOTE:

The authors believe that this is the first time a national survey of this kind and complexity has been conducted in Canada. Accordingly, every effort has been made to include the results of all parts of the analysis as these may prove to be instructive to other researchers. In this vein, Appendix B contains the details of the first two stages of the field survey data analysis (Section 3.1).

APPENDIX B1

SIDING MOISTURE READING

Variable No.			(Minor) Reading <15%	(Major) Reading >22%	
WEATHER DATA					
310	Degree days -18°C	heating	711	682	.
311	Degree days -18°C	drying	343	436	.
313	Driving Rain	heating	131	205	.
314	Driving Rain	drying	187	278	.
319	Vapour Pressure	heating	0.42	0.44	
320	Vapour Pressure	drying	0.71	0.67	
322	Solar Gain	heating	10 785	9 340	.
323	Solar Gain	drying	11 205	9 483	.
OCCUPANCY DATA					
225	# Permanent Residents		4.4	5.9	.
226	# People Home During Day		2.2	2.8	
243	# Loads of Wash/Week		4.1	6.5	.
247	Hang Clothes Inside	Y(1) N(2)	1.8	1.9	
253	Use Kitchen Exhaust	Y(1) N(2)	1.8	1.4	
HEATING AND HUMIDITY DATA					
259	Thermostat Setting °C day		19.6	19.1	
260	Thermostat Setting °C night		17.3	16.1	
263	Furnace Humidifier	Y(1) N(2) ?(3)	2.0	2.0	
277	Room Humidifier	Y(1) N(2) ?(3)	2.0	1.9	
278	Dehumidifier Summer	Y(1) N(2) ?(3)	2.0	1.9	
280	Air Out Houses	Y(1) N(2)	1.5	1.8	.
281	Frequency		3.8	5.0	.
282	Times People Exit House		2.9	2.4	.
283	Condensation Sept.-Oct.		1.7	1.4	.
286	Condensation January		1.2	1.0	
289	Condensation April		1.2	2.1	.
290	Condensation May-Aug.		1.8	2.8	.
295	Condensation Ceiling	Y(1) N(2) ?(3)	1.5	1.2	.
299	Cond. Master B.R.	Y(1) N(2) ?(3)	1.0	1.0	
301	Cond. Basement	Y(1) N(2) ?(3)	1.0	1.0	

APPENDIX B1
(Continued)

Variable No.			(Minor) Reading <15%	(Major) Reading >22%	
HOUSE DATA					
304	Year House Constructed		1971	1976	.
305	Retrofit	Y(1) N(2)	1.8	1.9	
306	Year of Retrofit		1980	1980	
307	Insulation Added		2.0	2.0	
MISCELLANEOUS READINGS					
9	RH Outside Time of Test		70.4	81.3	.
18	Shielding Factor		2.1	2.6	.
56	Ground Floor RH		45.7	50.7	.
88	Interior Control Moisture Reading		9.7	11.0	.
116	Wall Tightness	G(1) A(2) P(3)	2.0	2.1	
117	Window Tightness	G(1) A(2) P(3)	2.0	2.2	
118	Second Floor RH		48.7	51.3	.
173	Range Exhaust Outside		2.0	-	
174	Bathroom Exhaust Outside		1.8	1.4	
175	Fireplace	Y(1) N(2)	2.0	-	
176	Wood Stove	Y(1) N(2)	2.0	-	
187	Basement RH		52.0	58.3	.
195	Furnace Type		1.6	-	
197	Heating Type		2.7	3.0	.
213	Attic RH		69.1	86.0	.
221	Ceiling Tightness	G(1) A(2) P(3)	2.0	2.2	.

APPENDIX B2

BUCKLING OR WARPING OF SIDING

Variable No.			Minor	Major	
WEATHER DATA					
310	Degree days -18°C	heating	718	678	.
311	Degree days -18°C	drying	392	428	.
313	Driving Rain	heating	183	218	.
314	Driving Rain	drying	240	281	.
319	Vapour Pressure	heating	0.41	0.43	
320	Vapour Pressure	drying	0.70	0.67	
322	Solar Gain	heating	10 978	9 704	.
323	Solar Gain	drying	10 308	9 316	.
OCCUPANCY DATA					
225	# Permanent Residents		4.2	4.9	.
226	# People Home During Day		2.2	2.3	
243	# Loads of Wash/Week		5.0	5.1	
247	Hang Clothes Inside	Y(1) N(2)	1.6	1.8	
253	Use Kitchen Exhaust	Y(1) N(2)	1.6	1.5	
HEATING AND HUMIDITY DATA					
259	Thermostat Setting °C day		19.3	19.7	
260	Thermostat Setting °C night		16.7	16.7	
263	Furnace Humidifier	Y(1) N(2) ?(3)	2.0	2.1	
277	Room Humidifier	Y(1) N(2) ?(3)	1.9	2.0	
278	Dehumidifier Summer	Y(1) N(2) ?(3)	1.9	2.0	
280	Air Out Houses	Y(1) N(2)	1.6	1.7	
281	Frequency		4.2	4.5	
282	Times People Exit House		2.8	2.2	
283	Condensation Sept.-Oct.		1.8	1.1	.
286	Condensation January		1.2	1.0	
289	Condensation April		1.7	2.0	.
290	Condensation May-Aug.		2.3	2.3	
295	Condensation Ceiling	Y(1) N(2) ?(3)	1.4	1.4	
299	Cond. Master B.R.	Y(1) N(2) ?(3)	-	-	
301	Cond. Basement	Y(1) N(2) ?(3)	1.0	-	

APPENDIX B2
(Continued)

Variable No.			Minor	Major
HOUSE DATA				
304	Year House Constructed		1975	1976
305	Retrofit	Y(1) N(2)	1.7	2.0
306	Year of Retrofit		1980	-
307	Insulation Added		1.3	-
MISCELLANEOUS READINGS				
9	RH Outside Time of Test		65.3	71.6
18	Shielding Factor		2.2	2.5
56	Ground Floor RH		49.9	48.8
88	Interior Control Moisture Reading		9.2	10.9
116	Wall Tightness	G(1) A(2) P(3)	2.0	2.1
117	Window Tightness	G(1) A(2) P(3)	2.0	2.4
118	Second Floor RH		51	39
173	Range Exhaust Outside		1.8	-
174	Bathroom Exhaust Outside		1.3	1.8
175	Fireplace	Y(1) N(2)	2.0	-
176	Wood Stove	Y(1) N(2)	2.0	-
187	Basement RH		50.6	51.1
195	Furnace Type		2.7	1.0
197	Heating Type		2.8	2.8
213	Attic RH		66.8	78.5
221	Ceiling Tightness	G(1) A(2) P(3)	2.3	2.3

APPENDIX B3

PAINT DAMAGE ON SIDING

Variable No.			Minor	Major	
WEATHER DATA					
310	Degree days -18°C	heating	648	759	.
311	Degree days -18°C	drying	334	377	.
313	Driving Rain	heating	195	139	.
314	Driving Rain	drying	187	236	.
319	Vapour Pressure	heating	0.46	0.38	.
320	Vapour Pressure	drying	0.72	0.71	
322	Solar Gain	heating	9 940	11 280	.
323	Solar Gain	drying	10 928	10 613	
OCCUPANCY DATA					
225	# Permanent Residents		4.2	4.5	
226	# People Home During Day		2.0	2.8	.
243	# Loads of Wash/Week		4.4	4.5	
247	Hang Clothes Inside	Y(1) N(2)	1.7	1.8	
253	Use Kitchen Exhaust	Y(1) N(2)	1.8	1.5	
HEATING AND HUMIDITY DATA					
259	Thermostat Setting °C	day	19.2	20.3	
260	Thermostat Setting °C	night	17.0	15.8	.
263	Furnace Humidifier	Y(1) N(2) ?(3)	2.0	2.0	
277	Room Humidifier	Y(1) N(2) ?(3)	1.9	1.8	
278	Dehumidifier Summer	Y(1) N(2) ?(3)	1.9	2.8	.
280	Air Out Houses	Y(1) N(2)	1.5	1.7	
281	Frequency		3.3	4.5	.
282	Times People Exit House		2.5	2.5	
283	Condensation	Sept.-Oct.	1.5	1.6	
286	Condensation	January	1.1	1.0	
289	Condensation	April	1.3	1.2	
290	Condensation	May-Aug.	1.7	1.6	
295	Condensation Ceiling	Y(1) N(2) ?(3)	1.4	1.3	
299	Cond. Master B.R.	Y(1) N(2) ?(3)	1.0	1.0	
301	Cond. Basement	Y(1) N(2) ?(3)	1.0	1.0	

APPENDIX B3
(Continued)

Variable No.			Minor	Major
HOUSE DATA				
304	Year House Constructed		1975	1966
305	Retrofit	Y(1) N(2)	1.9	1.8
306	Year of Retrofit		1980	1981
307	Insulation Added		1.0	1.0
MISCELLANEOUS READINGS				
9	RH Outside Time of Test		78.0	53.2
18	Shielding Factor		2.0	2.4
56	Ground Floor RH		48.7	50.3
88	Interior Control Moisture Reading		9.8	10.3
116	Wall Tightness	G(1) A(2) P(3)	2.0	2.3
117	Window Tightness	G(1) A(2) P(3)	2.1	2.0
118	Second Floor RH		47.9	53.8
173	Range Exhaust Outside		2.0	-
174	Bathroom Exhaust Outside		1.3	1.3
175	Fireplace	Y(1) N(2)	-	-
176	Wood Stove	Y(1) N(2)	-	-
187	Basement RH		51.2	60.5
195	Furnace Type		2.3	-
197	Heating Type		2.9	3.0
213	Attic RH		73.2	70.5
221	Ceiling Tightness	G(1) A(2) P(3)	2.1	2.3

APPENDIX B4

SHEATHING MOISTURE READINGS

Variable No.			(Minor) Reading <15%	(Major) Reading >22%	
WEATHER DATA					
310	Degree days -18°C	heating	877	913	
311	Degree days -18°C	drying	341	488	.
313	Driving Rain	heating	50	241	.
314	Driving Rain	drying	118	205	.
319	Vapour Pressure	heating	0.30	0.29	
320	Vapour Pressure	drying	0.64	0.55	.
322	Solar Gain	heating	13 031	11 979	.
323	Solar Gain	drying	13 085	11 760	.
OCCUPANCY DATA					
225	# Permanent Residents		4.1	3.5	
226	# People Home During Day		2.1	-	
243	# Loads of Wash/Week		4.1	7.0	.
247	Hang Clothes Inside	Y(1) N(2)	1.8	2.0	
253	Use Kitchen Exhaust	Y(1) N(2)	2.0	1.0	
HEATING AND HUMIDITY DATA					
259	Thermostat Setting °C day		19.8	20.5	
260	Thermostat Setting °C night		19.3	18.0	
263	Furnace Humidifier	Y(1) N(2) ?(3)	2.0	2.0	
277	Room Humidifier	Y(1) N(2) ?(3)	2.0	1.5	.
278	Dehumidifier Summer	Y(1) N(2) ?(3)	2.0	1.5	.
280	Air Out Houses	Y(1) N(2)	1.5	1.5	
281	Frequency		3.0	5.0	.
282	Times People Exit House		2.7	2.5	
283	Condensation Sept.-Oct.		1.7	-	
286	Condensation January		1.1	1.0	
289	Condensation April		1.3	2.0	.
290	Condensation May-Aug.		2.0	-	
295	Condensation Ceiling	Y(1) N(2) ?(3)	1.5	1.0	.
299	Cond. Master B.R.	Y(1) N(2) ?(3)	1.0	-	
301	Cond. Basement	Y(1) N(2) ?(3)	-	1.0	

APPENDIX B4
(Continued)

Variable No.			(Minor) Reading <15%	(Major) Reading >22%
HOUSE DATA				
304	Year House Constructed		1972	1976
305	Retrofit	Y(1) N(2)	1.8	1.0
306	Year of Retrofit		1980	1980
307	Insulation Added		-	2.0
MISCELLANEOUS READINGS				
9	RH Outside Time of Test		65.9	77.5
18	Shielding Factor		1.9	3.0
56	Ground Floor RH		47.0	49.5
88	Interior Control Moisture Reading		9.3	9.0
116	Wall Tightness	G(1) A(2) P(3)	2.0	2.0
117	Window Tightness	G(1) A(2) P(3)	2.0	1.5
118	Second Floor RH		-	52.0
173	Range Exhaust Outside		-	-
174	Bathroom Exhaust Outside		-	1.0
175	Fireplace	Y(1) N(2)	-	-
176	Wood Stove	Y(1) N(2)	-	-
187	Basement RH		56.8	58.0
195	Furnace Type		1.8	-
197	Heating Type		2.5	3.0
213	Attic RH		58.9	57.0
221	Ceiling Tightness	G(1) A(2) P(3)	2.0	-

APPENDIX B5

MOULD AND MILDEW 1st FLOOR

Variable No.			Minor	Major	
WEATHER DATA					
310	Degree days -18°C	heating	721	688	.
311	Degree days -18°C	drying	352	348	
313	Driving Rain	heating	151	142	
314	Driving Rain	drying	186	217	.
319	Vapour Pressure	heating	0.41	0.41	
320	Vapour Pressure	drying	0.73	0.75	
322	Solar Gain	heating	11 111	11 115	
323	Solar Gain	drying	11 268	10 473	.
OCCUPANCY DATA					
225	# Permanent Residents		3.9	4.6	.
226	# People Home During Day		2.1	2.1	
243	# Loads of Wash/Week		4.7	5.0	
247	Hang Clothes Inside	Y(1) N(2)	1.8	1.7	
253	Use Kitchen Exhaust	Y(1) N(2)	1.6	1.6	
HEATING AND HUMIDITY DATA					
259	Thermostat Setting °C	day	19.9	19.0	.
260	Thermostat Setting °C	night	18.6	17.5	.
263	Furnace Humidifier	Y(1) N(2) ?(3)	2.0	2.1	
277	Room Humidifier	Y(1) N(2) ?(3)	1.9	1.9	
278	Dehumidifier Summer	Y(1) N(2) ?(3)	1.9	2.1	
280	Air Out Houses	Y(1) N(2)	1.4	1.4	
281	Frequency		4.1	3.0	.
282	Times People Exit House		2.4	2.7	
283	Condensation	Sept.-Oct.	1.7	1.5	.
286	Condensation	January	1.1	1.0	
289	Condensation	April	1.5	1.7	.
290	Condensation	May-Aug.	2.3	2.3	
295	Condensation Ceiling	Y(1) N(2) ?(3)	1.5	1.0	.
299	Cond. Master B.R.	Y(1) N(2) ?(3)	1.0	1.0	
301	Cond. Basement	Y(1) N(2) ?(3)	1.0	1.0	

APPENDIX B5
(Continued)

Variable No.			Minor	Major
HOUSE DATA				
304	Year House Constructed		1974	1976
305	Retrofit	Y(1) N(2)	1.7	1.7
306	Year of Retrofit		1980	1981
307	Insulation Added		1.5	1.3
MISCELLANEOUS READINGS				
9	RH Outside Time of Test		64.6	61.4
18	Shielding Factor		2.0	2.3
56	Ground Floor RH		49.6	53.8
88	Interior Control Moisture Reading		9.8	10.7
116	Wall Tightness	G(1) A(2) P(3)	2.0	2.1
117	Window Tightness	G(1) A(2) P(3)	1.8	1.9
118	Second Floor RH		51.8	55.0
173	Range Exhaust Outside		1.5	-
174	Bathroom Exhaust Outside		1.3	1.0
175	Fireplace	Y(1) N(2)	2.0	-
176	Wood Stove	Y(1) N(2)	2.0	-
187	Basement RH		52.4	54.8
195	Furnace Type		1.7	1.5
197	Heating Type		2.6	2.8
213	Attic RH		63.0	60.6
221	Ceiling Tightness	G(1) A(2) P(3)	2.1	2.3

APPENDIX B6

MOULD AND MILDEW 2nd FLOOR

Variable No.			Minor	Major	
WEATHER DATA					
310	Degree days -18°C	heating	590	599	.
311	Degree days -18°C	drying	365	347	.
313	Driving Rain	heating	239	209	.
314	Driving Rain	drying	247	243	
319	Vapour Pressure	heating	0.53	0.50	
320	Vapour Pressure	drying	0.78	0.77	
322	Solar Gain	heating	8 904	9 588	.
323	Solar Gain	drying	9 828	9 845	
OCCUPANCY DATA					
225	# Permanent Residents		4.2	4.8	.
226	# People Home During Day		1.8	3.0	.
243	# Loads of Wash/Week		5.1	4.7	
247	Hang Clothes Inside	Y(1) N(2)	1.8	1.6	
253	Use Kitchen Exhaust	Y(1) N(2)	1.6	1.0	.
HEATING AND HUMIDITY DATA					
259	Thermostat Setting °C day		19.9	20.5	
260	Thermostat Setting °C night		17.8	17.1	
263	Furnace Humidifier	Y(1) N(2) ?(3)	2.1	2.0	
277	Room Humidifier	Y(1) N(2) ?(3)	2.0	1.8	
278	Dehumidifier Summer	Y(1) N(2) ?(3)	1.9	1.8	
280	Air Out Houses	Y(1) N(2)	1.5	1.5	
281	Frequency		4.2	3.9	.
282	Times People Exit House		2.5	3.3	.
283	Condensation Sept.-Oct.		1.7	1.5	
286	Condensation January		1.2	1.2	
289	Condensation April		1.4	1.4	
290	Condensation May-Aug.		2.0	2.3	.
295	Condensation Ceiling	Y(1) N(2) ?(3)	1.6	1.5	
299	Cond. Master B.R.	Y(1) N(2) ?(3)	1.0	1.0	
301	Cond. Basement	Y(1) N(2) ?(3)	1.0	1.0	

APPENDIX B6
(Continued)

Variable No.			Minor	Major	
HOUSE DATA					
304	Year House Constructed		1973	1976	*
305	Retrofit	Y(1) N(2)	1.7	1.8	
306	Year of Retrofit		1980	1979	
307	Insulation Added		1.4	1.5	
MISCELLANEOUS READINGS					
9	RH Outside Time of Test		78.5	63.7	*
18	Shielding Factor		1.9	1.8	
56	Ground Floor RH		45.8	50.8	*
88	Interior Control Moisture Reading		9.8	9.6	
116	Wall Tightness	G(1) A(2) P(3)	1.9	1.9	
117	Window Tightness	G(1) A(2) P(3)	2.	1.9	
118	Second Floor RH		49.5	54.5	*
173	Range Exhaust Outside		1.6	2.	*
174	Bathroom Exhaust Outside		1.3	1.3	
175	Fireplace	Y(1) N(2)	2.	2.	
176	Wood Stove	Y(1) N(2)	2.	2.	
187	Basement RH		50.1	51.4	
195	Furnace Type		3.	3.	
197	Heating Type		3.	2.8	
213	Attic RH		80.8	76.4	*
221	Ceiling Tightness	G(1) A(2) P(3)	2.3	1.9	*

APPENDIX B7

CONDENSATION EVIDENCE ON WINDOWS

Variable No.			Minor	Major	
WEATHER DATA					
310	Degree days -18°C	heating	657	673	.
311	Degree days -18°C	drying	382	348	.
313	Driving Rain	heating	184	167	.
314	Driving Rain	drying	239	206	.
319	Vapour Pressure	heating	0.45	0.44	
320	Vapour Pressure	drying	0.71	0.74	
322	Solar Gain	heating	9.683	10 879	.
323	Solar Gain	drying	10 004	10 738	.
OCCUPANCY DATA					
225	# Permanent Residents		4.4	4.2	
226	# People Home During Day		2.2	2.2	
243	# Loads of Wash/Week		4.8	4.0	.
247	Hang Clothes Inside	Y(1) N(2)	1.7	1.8	
253	Use Kitchen Exhaust	Y(1) N(2)	1.5	1.6	
HEATING AND HUMIDITY DATA					
259	Thermostat Setting °C day		20.0	19.8	
260	Thermostat Setting °C night		17.2	17.7	
263	Furnace Humidifier	Y(1) N(2) ?(3)	2.0	2.0	
277	Room Humidifier	Y(1) N(2) ?(3)	1.9	1.8	
278	Dehumidifier Summer	Y(1) N(2) ?(3)	1.9	1.9	
280	Air Out Houses	Y(1) N(2)	1.5	1.5	
281	Frequency		3.4	3.3	
282	Times People Exit House		2.5	2.4	
283	Condensation Sept.-Oct.		1.6	1.7	
286	Condensation January		1.2	1.1	
289	Condensation April		1.4	1.6	
290	Condensation May-Aug.		1.7	2.4	
295	Condensation Ceiling	Y(1) N(2) ?(3)	1.4	1.3	
299	Cond. Master B.R.	Y(1) N(2) ?(3)	1.0	1.0	
301	Cond. Basement	Y(1) N(2) ?(3)	1.0	1.0	

APPENDIX B7
(Continued)

Variable No.			Minor	Major
HOUSE DATA				
304	Year House Constructed		1974	1977
305	Retrofit	Y(1) N(2)	1.7	1.7
306	Year of Retrofit		1980	1979
307	Insulation Added			
MISCELLANEOUS READINGS				
9	RH Outside Time of Test		73.5	66.0
18	Shielding Factor		2.1	2.3
56	Ground Floor RH		48.2	54.3
88	Interior Control Moisture Reading		10.1	10.1
116	Wall Tightness	G(1) A(2) P(3)	2.0	2.1
117	Window Tightness	G(1) A(2) P(3)	1.9	1.9
118	Second Floor RH		48.6	54.8
173	Range Exhaust Outside		1.7	2.0
174	Bathroom Exhaust Outside		1.4	1.2
175	Fireplace	Y(1) N(2)	2.0	2.0
176	Wood Stove	Y(1) N(2)	2.0	2.0
187	Basement RH		54.0	53.5
195	Furnace Type		1.5	1.7
197	Heating Type		2.8	2.6
213	Attic RH		77.5	57.8
221	Ceiling Tightness	G(1) A(2) P(3)	2.1	2.1

APPENDIX B8

1st FLOOR STUD MOISTURE READINGS

Variable No.			(Minor) Reading <15%	(Major) Reading >22%	
WEATHER DATA					
310	Degree days -18°C	heating	709	730	.
311	Degree days -18°C	drying	361	393	.
313	Driving Rain	heating	167	224	.
314	Driving Rain	drying	196	206	.
319	Vapour Pressure	heating	0.43	0.43	
320	Vapour Pressure	drying	0.72	0.69	
322	Solar Gain	heating	10 500	11 214	.
323	Solar Gain	drying	11 109	11 045	.
OCCUPANCY DATA					
225	# Permanent Residents		4.3	4.3	
226	# People Home During Day		2.2	2.3	
243	# Loads of Wash/Week		4.9	3.3	.
247	Hang Clothes Inside	Y(1) N(2)	1.8	1.7	
253	Use Kitchen Exhaust	Y(1) N(2)	1.7	1.7	
HEATING AND HUMIDITY DATA					
259	Thermostat Setting °C	day	20.1	20.0	
260	Thermostat Setting °C	night	18.4	19.7	.
263	Furnace Humidifier	Y(1) N(2) ?(3)	2.0	2.0	
277	Room Humidifier	Y(1) N(2) ?(3)	2.0	2.0	
278	Dehumidifier Summer	Y(1) N(2) ?(3)	2.0	2.0	
280	Air Out Houses	Y(1) N(2)	1.5	1.7	.
281	Frequency		4.0	4.0	
282	Times People Exit House		2.7	2.3	.
283	Condensation Sept.-Oct.		1.6	2.0	
286	Condensation January		1.1	1.0	
289	Condensation April		1.4	1.0	.
290	Condensation May-Aug.		1.9	2.0	
295	Condensation Ceiling	Y(1) N(2) ?(3)	1.5	1.3	
299	Cond. Master B.R.	Y(1) N(2) ?(3)	1.0	1.0	
301	Cond. Basement	Y(1) N(2) ?(3)	1.0	-	

APPENDIX B8
(Continued)

Variable No.			(Minor) Reading <15%	(Major) Reading >22%
HOUSE DATA				
304	Year House Constructed		1974	1978
305	Retrofit	Y(1) N(2)	1.8	-
306	Year of Retrofit		1980	-
307	Insulation Added		1.5	-
MISCELLANEOUS READINGS				
9	RH Outside Time of Test		69.8	81.5
18	Shielding Factor		2.0	2.3
56	Ground Floor RH		45.8	55.0
88	Interior Control Moisture Reading		9.6	10.3
116	Wall Tightness	G(1) A(2) P(3)	2.0	2.0
117	Window Tightness	G(1) A(2) P(3)	1.9	2.0
118	Second Floor RH		48.3	47.0
173	Range Exhaust Outside		-	-
174	Bathroom Exhaust Outside		1.4	1.5
175	Fireplace	Y(1) N(2)		
176	Wood Stove	Y(1) N(2)		
187	Basement RH		50.9	48.0
195	Furnace Type			
197	Heating Type		2.6	3.0
213	Attic RH		70.9	68.0
221	Ceiling Tightness	G(1) A(2) P(3)	2.0	2.5

APPENDIX B9

MOISTURE READINGS IN 2nd FLOOR STUDS

Variable No.			(Minor) Reading <15%	(Major) Reading >22%	
WEATHER DATA					
310	Degree days -18°C	heating	567	821	.
311	Degree days -18°C	drying	366	462	.
313	Driving Rain	heating	254	249	.
314	Driving Rain	drying	252	228	.
319	Vapour Pressure	heating	0.56	0.36	.
320	Vapour Pressure	drying	0.79	0.62	.
322	Solar Gain	heating	8 466	10 874	.
323	Solar Gain	drying	9 708	11 067	.
OCCUPANCY DATA					
225	# Permanent Residents		4.4	3.9	.
226	# People Home During Day		1.9	1.4	.
243	# Loads of Wash/Week		5.0	4.2	.
247	Hang Clothes Inside	Y(1) N(2)	1.7	1.7	
253	Use Kitchen Exhaust	Y(1) N(2)	1.7	1.7	
HEATING AND HUMIDITY DATA					
259	Thermostat Setting °C day		19.7	18.9	.
260	Thermostat Setting °C night		17.8	17.4	.
263	Furnace Humidifier	Y(1) N(2) ?(3)	2.0	2.0	
277	Room Humidifier	Y(1) N(2) ?(3)	2.0	2.0	
278	Dehumidifier Summer	Y(1) N(2) ?(3)	-	2.0	
280	Air Out Houses	Y(1) N(2)	1.5	1.5	
281	Frequency		4.2	4.0	
282	Times People Exit House		2.5	2.1	
283	Condensation Sept.-Oct.		1.7	1.8	
286	Condensation January		1.4	1.0	
289	Condensation April		1.5	1.4	
290	Condensation May-Aug.		2.1	1.8	.
295	Condensation Ceiling	Y(1) N(2) ?(3)	1.7	1.5	
299	Cond. Master B.R.	Y(1) N(2) ?(3)	1.0	1.0	
301	Cond. Basement	Y(1) N(2) ?(3)	-	-	

APPENDIX B9
(Continued)

Variable No.			(Minor) Reading <15%	(Major) Reading >22%	
HOUSE DATA					
304	Year House Constructed		1979	1974	
305	Retrofit	Y(1) N(2)	1.5	2.0	.
306	Year of Retrofit		1980	-	.
307	Insulation Added		1.5	-	
MISCELLANEOUS READINGS					
9	RH Outside Time of Test		80.7	74.4	.
18	Shielding Factor		1.9	1.9	
56	Ground Floor RH		44.1	49.3	.
88	Interior Control Moisture Reading		9.5	10.5	.
116	Wall Tightness	G(1) A(2) P(3)	1.9	2.0	
117	Window Tightness	G(1) A(2) P(3)	2.1	1.9	
118	Second Floor RH		47.8	52.3	.
173	Range Exhaust Outside		1.0	-	
174	Bathroom Exhaust Outside		1.4	1.3	
175	Fireplace	Y(1) N(2)	-	-	
176	Wood Stove	Y(1) N(2)	-	-	
187	Basement RH		44.8	53.3	.
195	Furnace Type		3.0	3.0	
197	Heating Type		2.9	3.0	
213	Attic RH		82.9	75.5	.
221	Ceiling Tightness	G(1) A(2) P(3)	2.2	1.8	.

APPENDIX B10

ATTIC MOISTURE READINGS

Variable No.			(Minor) Reading <15%	(Major) Reading >22%	
WEATHER DATA					
310	Degree days -18°C	heating	755	634	.
311	Degree days -18°C	drying	351	447	.
313	Driving Rain	heating	128	241	.
314	Driving Rain	drying	175	316	.
319	Vapour Pressure	heating	0.39	0.46	.
320	Vapour Pressure	drying	0.75	0.65	.
322	Solar Gain	heating	11 417	8 635	.
323	Solar Gain	drying	11 627	8 520	.
OCCUPANCY DATA					
225	# Permanent Residents		4.2	6.5	.
226	# People Home During Day		2.1	1.5	.
243	# Loads of Wash/Week		5.0	6.0	
247	Hang Clothes Inside	Y(1) N(2)	1.8	1.6	
253	Use Kitchen Exhaust	Y(1) N(2)	1.6	1.8	
HEATING AND HUMIDITY DATA					
259	Thermostat Setting °C day		20.0	20.6	
260	Thermostat Setting °C night		19.1	14.4	.
263	Furnace Humidifier	Y(1) N(2) ?(3)	2.0	2.0	
277	Room Humidifier	Y(1) N(2) ?(3)	1.9	2.0	
278	Dehumidifier Summer	Y(1) N(2) ?(3)	2.0	2.0	
280	Air Out Houses	Y(1) N(2)	1.5	2.0	.
281	Frequency		3.5	-	
282	Times People Exit House		2.7	3.2	.
283	Condensation Sept.-Oct.		1.7	1.2	.
286	Condensation January		1.1	1.0	
289	Condensation April		1.3	1.8	.
290	Condensation May-Aug.		1.9	2.2	.
295	Condensation Ceiling	Y(1) N(2) ?(3)	1.6	1.0	.
299	Cond. Master B.R.	Y(1) N(2) ?(3)	1.0	1.0	
301	Cond. Basement	Y(1) N(2) ?(3)	1.0	-	

APPENDIX B10
(Continued)

Variable No.			(Minor) Reading <15%	(Major) Reading >22%	
HOUSE DATA					
304	Year House Constructed		1975	1976	
305	Retrofit	Y(1) N(2)	1.8	2.0	
306	Year of Retrofit		1981	-	
307	Insulation Added		1.3	-	
MISCELLANEOUS READINGS					
9	RH Outside Time of Test		71.5	78.8	.
18	Shielding Factor		1.9	2.5	
56	Ground Floor RH		47.5	52.3	.
88	Interior Control Moisture Reading		10.2	9.8	
116	Wall Tightness	G(1) A(2) P(3)	2.0	2.0	
117	Window Tightness	G(1) A(2) P(3)	1.7	2.2	.
118	Second Floor RH		49.5	51.0	
173	Range Exhaust Outside		1.0	1.0	
174	Bathroom Exhaust Outside		1.4	1.0	.
175	Fireplace	Y(1) N(2)	-	-	
176	Wood Stove	Y(1) N(2)	-	-	
187	Basement RH		54.6	54.5	
195	Furnace Type		1.5	-	
197	Heating Type		2.5	3.0	
213	Attic RH		65.3	99.0	.
221	Ceiling Tightness	G(1) A(2) P(3)	2.3	2.2	
206	Type of Attic Insulation		2.4	1.3	.
207	Thickness of Insulation		6.6	5.5	.
208	Wetness of Insulation		1.0	2.5	.
209	Wetness Localized		1.0	1.0	
210	V.B. Damaged		1.0	1.0	
211	Over Partition Walls		1.0	1.0	
212	Seal on Access Hatch	G(1) P(2)	1.6	1.4	
218	# Roof Vents		2.1	1.7	.
219	Soffit Vents Free	Y(1) N(2)	1.2	1.8	.

APPENDIX B11

MOULD AND MILDEW IN ATTIC STRUCTURE

Variable No.			Minor	Major
WEATHER DATA				
310	Degree days -18°C	heating	708	597
311	Degree days -18°C	drying	388	342
313	Driving Rain	heating	165	197
314	Driving Rain	drying	256	247
319	Vapour Pressure	heating	0.40	0.51
320	Vapour Pressure	drying	0.70	0.80
322	Solar Gain	heating	10 791	9 549
323	Solar Gain	drying	9 874	9 788
OCCUPANCY DATA				
225	# Permanent Residents		4.3	4.5
226	# People Home During Day		2.3	2.4
243	# Loads of Wash/Week		4.4	4.9
247	Hang Clothes Inside	Y(1) N(2)	1.6	1.8
253	Use Kitchen Exhaust	Y(1) N(2)	1.4	1.7
HEATING AND HUMIDITY DATA				
259	Thermostat Setting °C day		19.5	19.3
260	Thermostat Setting °C night		17.1	16.4
263	Furnace Humidifier	Y(1) N(2) ?(3)	2.1	2.0
277	Room Humidifier	Y(1) N(2) ?(3)	1.9	1.9
278	Dehumidifier Summer	Y(1) N(2) ?(3)	1.9	1.9
280	Air Out Houses	Y(1) N(2)	1.6	1.5
281	Frequency		3.2	4.2
282	Times People Exit House		2.4	2.6
283	Condensation Sept.-Oct.		1.7	1.6
286	Condensation January		1.3	1.1
289	Condensation April		2.1	1.7
290	Condensation May-Aug.		2.4	2.7
295	Condensation Ceiling	Y(1) N(2) ?(3)	1.3	1.4
299	Cond. Master B.R.	Y(1) N(2) ?(3)	1.0	1.0
301	Cond. Basement	Y(1) N(2) ?(3)	1.0	1.0

APPENDIX B11
(Continued)

Variable No.			Minor	Major
HOUSE DATA				
304	Year House Constructed		1976	1976
305	Retrofit	Y(1) N(2)	1.7	1.8
306	Year of Retrofit		1979	1980
307	Insulation Added		1.6	1.0
MISCELLANEOUS READINGS				
9	RH Outside Time of Test		59.0	72.7
18	Shielding Factor		2.4	2.2
56	Ground Floor RH		47.6	56.0
88	Interior Control Moisture Reading		9.7	9.7
116	Wall Tightness	G(1) A(2) P(3)	2.1	2.1
117	Window Tightness	G(1) A(2) P(3)	2.1	1.8
118	Second Floor RH		44.7	53.1
173	Range Exhaust Outside		1.0	1.8
174	Bathroom Exhaust Outside		1.3	1.5
175	Fireplace	Y(1) N(2)	-	2.0
176	Wood Stove	Y(1) N(2)	-	2.0
187	Basement RH		50.7	51.0
195	Furnace Type		1.0	3.0
197	Heating Type		2.9	2.8
213	Attic RH		67.2	69.6
221	Ceiling Tightness	G(1) A(2) P(3)	2.5	2.7
206	Type of Attic Insulation		1.7	1.2
207	Thickness of Insulation		5.8	6.1
208	Wetness of Insulation		1.4	1.4
209	Wetness Localized		1.0	1.0
210	V.B. Damaged		1.0	1.0
211	Over Partition Walls		1.0	1.0
212	Seal on Access Hatch	G(1) P(2)	1.7	1.8
218	# Roof Vents		1.9	1.7
219	Soffit Vents Free	Y(1) N(2)	1.4	1.9

APPENDIX B

LEGEND

Variable No.			Minor	Major
			units or Reading	
WEATHER DATA				
310	Degree days -18°C	heating		
311	Degree days -18°C	drying		
313	Driving Rain	heating		
314	Driving Rain	drying		av/month
319	Vapour Pressure	heating		kilo Pascals-av/month
320	Vapour Pressure	drying		
322	Solar Gain	heating		mega-Joules/m^2
323	Solar Gain	drying		av/month
OCCUPANCY DATA				
225	# Permanent Residents			-
226	# People Home During Day			-
243	# Loads of Wash/Week			-
247	Hang Clothes Inside	Y(1) N(2)		-
253	Use Kitchen Exhaust	Y(1) N(2)		-
HEATING AND HUMIDITY DATA				
259	Thermostat Setting °C day			av. daytime reading
260	Thermostat Setting °C night			av. night reading
263	Furnace Humidifier	Y(1) N(2) ?(3)		-
277	Room Humidifier	Y(1) N(2) ?(3)		-
278	Dehumidifier Summer	Y(1) N(2) ?(3)		-
280	Air Out Houses	Y(1) N(2)		-
281	Frequency			Q 11(b) Occup. Surv.
282	Times People Exit House			Q 12 Occup. Surv.
283	Condensation Sept.-Oct.			Yes = 1 to Never = 3
286	Condensation January			Yes = 1 to Never = 3
289	Condensation April			Yes = 1 to Never = 3
290	Condensation May-Aug.			Yes = 1 to Never = 3
295	Condensation Ceiling	Y(1) N(2) ?(3)		-
299	Cond. Master B.R.	Y(1) N(2) ?(3)		-
301	Cond. Basement	Y(1) N(2) ?(3)		-

APPENDIX B
(Continued)

Variable No.			Minor	Major
			units or Reading	
HOUSE DATA				
304	Year House Constructed			-
305	Retrofit	Y(1) N(2)		-
306	Year of Retrofit			-
307	Insulation Added			Q 15(c) Occup. Surv.
MISCELLANEOUS READINGS				
9	RH Outside Time of Test			percent
18	Shielding Factor			Q 2.6 Physical Surv.
56	Ground Floor RH			percent
88	Interior Control Moisture Reading			percent
116	Wall Tightness	G(1) A(2) P(3)		-
117	Window Tightness	G(1) A(2) P(3)		-
118	Second Floor RH			percent
173	Range Exhaust Outside			Yes (1) No (2)
174	Bathroom Exhaust Outside			Yes (1) No (2)
175	Fireplace	Y(1) N(2)		-
176	Wood Stove	Y(1) N(2)		-
187	Basement RH			percent
195	Furnace Type			Q 6.11 Physical Surv.
197	Heating Type			Q 6.12 Physical Surv.
213	Attic RH			percent
221	Ceiling Tightness	G(1) A(2) P(3)		-

. Tested for statistical significance

heating = heating season December through March
drying = drying season April, May

Note: where reference to questions in the survey for units or measurements. Please see Appendix A.

APPENDIX C

EXPECTED PROBLEMS BY REGION

TABLE C1

MOISTURE INDUCED PROBLEMS IN HOUSING
YEAR OF CONSTRUCTION OF NHA HOUSING PROJECTED TO HAVE PROBLEMS[1)]

NEWFOUNDLAND REGION

House Type	Year																	
	Pre 1970		1970-75		1976		1977		1978		1979		1980		1981		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Single Family	30	(2.6)	417	(36.2)	229	(19.8)	189	(16.4)	166	(14.4)	82	(7.1)	40	(3.5)	-	-	1,153	(100)
Semi Detached, Row, Duplex, Triplex	-	-	50	(3.0)	1,594	(96.1)	8	(0.5)	-	-	8	(0.5)	-	-	-	-	1,660	(100)
Mobile/Modular	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apartments	-	-	-	-	40	(100)	-	-	-	-	-	-	-	-	-	-	40	(100)
TOTAL	30	(1.1)	467	(16.3)	1,863	(65.3)	197	(6.9)	166	(5.8)	90	(3.2)	40	(1.4)	-	-	2,853	(100)

1) Estimated Total (See Table 5.2)

Note: The base data from which this table is developed is very incomplete - Read with caution

TABLE C2

MOISTURE INDUCED PROBLEMS IN HOUSING
YEAR OF CONSTRUCTION OF NHA HOUSING PROJECTED TO HAVE PROBLEMS[1)]

MARITIMES REGION

House Type	Year																	
	Pre 1970		1970-75		1976		1977		1978		1979		1980		1981		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Single Family	-	-	65	(36.5)	12	(6.8)	23	(12.9)	39	(21.9)	12	(6.8)	4	(2.2)	23	(12.9)	178	(100)
Semi Detached, Row, Duplex, Triplex	-	-	94	(87.9)	13	(12.1)	-	-	-	-	-	-	-	-	-	-	107	(100)
Mobile/Modular	-	-	-	-	-	-	-	-	3	(42.9)	-	-	-	-	4	(57.1)	7	(100)
Apartments	120	(64.5)	66	(35.5)	-	-	-	-	-	-	-	-	-	-	-	-	186	(100)
TOTAL	120	(25.1)	225	(47.2)	25	(5.2)	23	(4.8)	42	(8.8)	12	(2.5)	4	(0.8)	27	(5.6)	478	(100)

1) Estimated Total (See Table 5.2)

Note: The base data from which this table is developed is very incomplete - Read with caution

TABLE C3

MOISTURE INDUCED PROBLEMS IN HOUSING
YEAR OF CONSTRUCTION OF NHA HOUSING PROJECTED TO HAVE PROBLEMS[1)]

QUEBEC REGION

House Type	Year																	
	Pre 1970		1970-75		1976		1977		1978		1979		1980		1981		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Single Family *	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Semi Detached, Row, Duplex, Triplex	-	-	159	(98.1)	3	(1.9)	-	-	-	-	-	-	-	-	-	-	162	(100)
Mobile/Modular	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apartments	-	-	876	(100)	-	-	-	-	-	-	-	-	-	-	-	-	876	(100)
TOTAL	-	-	1,035	(99.7)	3	(0.3)	-	-	-	-	-	-	-	-	-	-	1,038	(100)

1) Estimated Total (See Table 5.2)

* Only six units reported from entire Quebec Region

Note: The base data from which this table is developed is very incomplete - Read with caution

TABLE C4

MOISTURE INDUCED PROBLEMS IN HOUSING
YEAR OF CONSTRUCTION OF NHA HOUSING PROJECTED TO HAVE PROGLEMS[1)]

ONTARIO REGION

House Type	Year																	
	Pre 1970		1970-75		1976		1977		1978		1979		1980		1981		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Single Family	19	(8.4)	71	(31.6)	16	(7.1)	49	(21.8)	17	(7.6)	18	(8.0)	16	(7.1)	19	(8.4)	225	(100)
Semi Detached, Row, Duplex, Triplex	206	(34.7)	222	(37.4)	-	-	25	(4.2)	33	(5.6)	36	(6.1)	71	(12.0)	-	-	593	(100)
Mobile/Modular	-	-	2	(11.1)	8	(44.5)	-	-	6	(33.3)	2	(11.2)	-	-	-	-	18	(100)
Apartments	-	-	485	(47.9)	-	-	114	(11.3)	413	(40.8)	-	-	-	-	-	-	1,012	(100)
TOTAL	225	(12.2)	780	(42.2)	24	(1.3)	188	(10.2)	469	(25.4)	56	(3.0)	87	(4.7)	19	(1.0)	1,848	(100)

1) Estimated Total (See Table 5.2)

Note: The base data from which this table is developed is very incomplete - Read with caution

TABLE C5

MOISTURE INDUCED PROBLEMS IN HOUSING
YEAR OF CONSTRUCTION OF NHA HOUSING PROJECTED TO HAVE PROBLEMS[1)]

PRAIRIE REGION

House Type	Year																	
	Pre 1970		1970-75		1976		1977		1978		1979		1980		1981		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Single Family	44	(11.3)	36	(9.3)	55	(14.2)	10	(2.6)	4	(1.0)	234	(60.4)	-	-	5	(1.2)	388	(100)
Semi Detached,[2)] Row, Duplex, Triplex	853	(64.0)	479	(36.0)	-	-	-	-	-	-	-	-	-	-	-	-	1,332	(100)
Mobile/Modular	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apartments	-	-	125	(88.0)	-	-	-	-	-	-	-	-	17	(12.0)	-	-	142	(100)
TOTAL	897	(48.1)	640	(34.4)	55	(3.0)	10	(0.5)	4	(0.2)	234	(12.6)	17	(0.9)	5	(0.3)	1,862	(100)

1) Estimated Total (See Table 5.2)

2) These units were only recently taken over by CMHC

Note: The base data from which this table is developed is very incomplete - Read with caution.

TABLE C6

MOISTURE INDUCED PROBLEMS IN HOUSING
YEAR OF CONSTRUCTION OF NHA HOUSING PROJECTED TO HAVE PROBLEMS[1)]

BRITISH COLUMBIA REGION

House Type	Year																	
	Pre 1970		1970-75		1976		1977		1978		1979		1980		1981		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Single Family	2	(6.0)	-	-	5	(15.2)	5	(15.2)	5	(15.2)	-	-	4	(12.0)	12	(36.4)	33	(100)
Semi Detached, Row, Duplex, Triplex	-	-	1,143	(68.7)	241	(14.5)	279	(16.8)	-	-	-	-	-	-	-	-	1,663	(100)
Mobile/Modular	-	-	-	-	-	-	14	(13.0)	14	(13.0)	14	(13.0)	14	(13.0)	52	(48.0)	108	(100)
Apartments	-	-	334	(91.0)	33	(9.0)	-	-	-	-	-	-	-	-	-	-	367	(100)
TOTAL	2	(0.1)	1,477	(68.1)	279	(12.9)	298	(13.7)	19	(0.9)	14	(0.6)	18	(0.8)	64	(2.9)	2,171	(100)

1) Estimated Total (See Table 5.2)

Note: The base data from which this table is developed is very incomplete - Read with caution

Number/
Numéro

2

Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

MOISTURE INDUCED PROBLEMS IN NHA HOUSING

PART 2 OF A 3 PART SERIES

LITERATURE REVIEW AND RESEARCH

Prepared For:
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Policy Development and Research Sector
of
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Caution

The analyses, interpretations and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation, which assisted in the study and its publications. The results of the study are published for information purposes and the reader is cautioned that the statistical and scientific data generated herein are derived from a study of a select few Canadian moisture-troubled homes.

Extrapolation of this data to most houses in Canada and to houses in other countries and climates may be feasible, provided that the vagaries of climates and the behaviour of housing systems and building materials in those areas are understood.

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EXECUTIVE SUMMARY

1.0 Background

This report summarizes the results of an extensive review of available literature in the area of moisture and its potential problems in housing*. In addition:

- o the specific moisture related problems identified in the course of this project** are investigated;
- o structural details which were observed to lead to moisture problems are discussed;
- o possible solutions both for new and retrofit housing are suggested;
- o the need for further laboratory and field research programs is identified;

Specifically, this report discusses the following:

- o Airtightness and its contribution to moisture related problems;
- o Mould and mildew inside the house;
- o Window condensation;
- o Attic condensation;
- o Concealed wall condensation;
- o Siding problems;
- o Observations.

---

* Although the consulting contract specifically identified NHA housing, the discussions in this report are more generally applicable.

** CMHC contract 176-4-25 with Marshall Macklin Monaghan Limited.

2.0 Findings

Based on the work undertaken during the research and other phases of this project, the consultant is of the opinion that, although localized rotting of wall structural members may exist, especially in areas where there is a defect in the vapour barrier, wholesale failure of framing members and structural collapse is not expected to occur.

Generally speaking, the moisture content of the wall cavities was quite low. Moisture readings in the structural members ranged from close to saturation during the winter at the cold outside surface, to dry at the warm inside face.

The study identified mould and mildew growth as being very wide-spread. Although not a structural problem, this is perceived as an aesthetic, psychological and, possibly, a health problem. (There are references in the literature to the detrimental health effects of mould and mildew growth.)

Attics were found to be prone to attack by high humidities. Unless adequately vented, and isolated from the living space with a proper air barrier, and also vapour barriers, structural collapse of roof systems is possible.

What is, perhaps, a unique finding of this study is the significant impact of meso-climate (regional climatic conditions), on the manifestation of the various problems. During the winter, moisture will enter the wall system in most housing. In dry, cold, sunny climates such as Thompson, Manitoba, the wall cavity dries out in the spring. In Newfoundland, where the climate is continually wet with low solar gains, walls do not dry and, although not wide-spread, isolated cases of rot within the wall cavity were observed during our field investigations.

Although an attempt was made to isolate the relative importance of inside and outside moisture on the observed siding problem (primarily in Newfoundland), it was not possible to come to any definite conclusions, other than to note that both contribute to some degree. However, if the siding is separated from the sheathing by means of furring strips, problems should not re-occur. In addition, the solar energy collected in the space, thus created, will promote drying of both the siding and sheathing, provided the space is properly vented.

High condensation on windows is an aesthetic problem. Although this could cause localized rot, costly damage to structural members is not expected.

Sources of moisture are identified and discussed, as most affect the performance of the building structure. These sources are:

- outside moisture (air moisture content, driving rain);
- inside moisture (generated by the house occupant);
- moisture from the basement.

Also discussed are:

- moisture within the wall cavity;
- moisture between the sheathing and siding;

3.0 Conclusions

The process of movement of the liquid water and water vapour in and out of the wall, and its storage within the wall, is a complex process. The general understanding of the process is further confused by most research done to date, which uses highly idealized models to predict heat, moisture and air flow. While these models may be valid under steady state conditions and in ideal circumstances, conditions in real structures are far from ideal. Moreover, single component effects can

not always be superimposed. Similarly, laboratory evaluations dealing with one variable at a time, such as the effect of moisture diffusion on wall moisture build-up, are of limited value as they ignore the effect of moisture transport by air leakage.

Moisture deposited in attic spaces can come from within the house or from outside sources such as snow and external high humidity conditions. The amount of moisture deposited is a function of total moisture available, surface temperatures of the sheathing and structural members and the amount of attic ventilation. Simplistic modelling is, therefore, not appropriate to determine the net moisture available in attic spaces.

As was found in other countries, there is a very significant gap between what is known and published (regarding moisture and its effect on housing) and what is actually practiced. A strong recommendation is made that better and more effective means of communicating this knowledge to the professions and trades, must therefore, be established.

It is also recommended that, with pressures for retrofit, new products, energy conservation, etc., an effort must be made to co-ordinate these various aspects and examine them in totality. Only the results of such a global investigation will pinpoint areas where current actions could lead to future longterm problems. A unique organization, with broad ranging powers and having the technical capability to engage in building system research, would be one method of co-ordinating the various pressures and identifying where knowledge is lacking.

The identification of the impact of local weather on observed problems leads to the recommendation that the various building codes recognize this phenomenon. Perhaps a performance code, with typical examples of how the required standards could be met in the various geographic regions, would accomplish this.

1.0 INTRODUCTION

1.1 General

The following report summarizes the results of a review of literature and available research pertaining specifically to moisture and its effect on various building components individually, but more particularly, as a system.

Although each individual building component may be adequate in its performance, recent moves towards airtight, more highly insulated houses have resulted in moisture related problems. Localized rotting in sheathing and in structural members, especially in areas where the vapour barrier is interrupted, high levels of condensation and mould and mildew growth, both within the house itself and within attics and crawl spaces, are all problems that have been reported.

To supplement the material contained in the literature, the consultants removed the siding and sheathing and investigated parts of the wall cavity of 5 units where problems were reported. The consultant also conducted a detailed (non-destructive) nation wide field investigation of 201 "troubled" housing units and interviewed their occupants.

The results of this investigation and a statistical analysis of the results have identified a number of factors which can be shown to be highly correlated to the degree of damage observed.*

The material contained in this report draws from the other work; it investigates current building systems and their tolerance to the various internal and external moisture loadings; and makes preliminary recommendations for improvements that could be made, or changes necessary, to increase the resistance of Canadian housing units to moisture problems.

---

* Analysis of Field Survey Results and Projections of Future Problems Marshall Macklin Monaghan, November, 1982. Part 1 of CMHC Contract 176-4-25.

In addition, recommendations are made pertaining to further field and laboratory research that will be required to confirm, or refine the recommendations and conclusions of this study.

Although an extensive literature review was undertaken covering titles from North America, as well as Europe, it quickly became evident that the topic of building system behaviour with respect to moisture was not well documented. In fact, the best available data was (in an unpublished form), from some of the building product manufacturers.

The titles listed in this report summarize most of the relevant published work on this topic.

The results of the literature review are, therefore, not published here, but references to the most important papers are made throughout the report where they are appropriate or particularly relevant.

1.2 Historical Overview

The log dwellings of the early settlers in Canada were free from moisture problems, as long as the roof did not leak and the logs were kept from coming in contact with the soil. Indoor relative humidity was undoubtedly low during the heating season, due to two factors:

- o natural ventilation caused by wind and stack effect;
- o infiltration while heating with an open fireplace.

Dating back to the iron age, the log buildings of northern Europe had gone through a long evolutionary process - a process which sorted out bad details and passed on proven techniques.

With increased affluence, the wood frame building, which was more economical on the use of wood, replaced the log building. The 2 in.

x 4 in. (38 mm x 89 mm) frame buildings, first the balloon frame and later the platform frame, evolved from the 1830's and have remained essentially unchanged. Condensation was not a problem, as the frame buildings were still draughty and lacked vapour retarding materials.

By 1900, the use of thermal insulation to reduce heating costs and increase comfort, came to be appreciated[1)]. Development of wood fibre and asphalt siding material appeared on the market and, when tightly applied with sealed joints, these materials provided a tight, vapour-resistant seal. Subsequent to these product developments, rotting of frame walls within the building system, was first reported.

Similarly, the use of thermal insulation was suspected as a possible cause for decay of some wood products within the wall system. Studies in the United States, in 1935, and later in Canada, demonstrated that wetting takes place on the cold side of the insulation. Vapour barriers were recommended to limit the entry of water vapour into insulated walls and roofs[1)].

The 1973 oil embargo provided the impetus to make a number of major changes to the building enclosure in order to reduce energy consumption.

Two of these were:

- more careful attention to the use of a continuous air/vapour barrier, as a means to decrease air infiltration;

- the installation of more thermal insulation, particularly in the attic where extra insulation could be placed without the need to change traditional framing dimensions or practices.

At the same time, further design changes were induced by an increase in the demand for low cost and social housing. To reduce land costs, row housing developments became prevalent. Here, the

replacement of exterior walls by partition walls, reduced the unit's average number of air changes. The installation of relatively inexpensive electric baseboard heating eliminated chimneys, further decreasing the number of air changes and interior air circulation.

The above changes substantially reduced the dilution rate of moisture and pollutants in the indoor air. Fan pressure testing of detached housing in the Saskatoon area has demonstrated the general increase in the airtightness of housing in the recent years. At a 50 Pa overpressure, the number of air changes per hour (ac/h) was 10.35 for pre-1945 housing, 4.55 for 1946-1960 housing and 3.57 for housing constructed between 1961-1980[2)].

While fan pressure testing was not carried out as part of the present study, it would be reasonable to assume that post 1975 row housing would generally exhibit less than 3.57 ac/h at 50 Pa over pressure.

At a constant rate of indoor moisture production, a decrease in the number of air changes means a corresponding increase in indoor relative humidity. While there is a lack of systematic data on inside relative humidities in Canadian housing, a comparison between relative humidity values obtained in various parts of Canada between 1957 and 1961[3)] and those obtained in the present investigation shows, as expected, a substantial increase.*

It further appears that a feed-back mechanism is established. A decrease in air infiltration increases indoor relative humidity, which in turn leads to a dimensional change in framing members, further reducing the rate of infiltration as cracks through which air movement takes place close due to swelling. An increase in the indoor relative humidity from 20 to 40 pecent was shown, in one study, to decrease heating costs by up to 50 percent[10)].

---

* Observed RH values in problem houses were in the 50% range as compared to 35% average values reported in the 1957-1961 study. It should be noted that most houses investigated as "problem" houses were electrically heated. It is expected that houses with a heating system with a flue will still exhibit internal RH values similar to those reported in the above study.

At the same time, the ability of the building envelope to cope with the increased moisture loading has, if anything, decreased. For instance, the inappropriate use of lower cost cladding materials which usually have low moisture permeability and, thus, lower moisture storage capacity were noticed to cause problems. In some areas, such as the major population centres in Newfoundland, the rapid growth in housing demand also taxed the supply of skilled workers; leading to deficiencies in important detailing in some new houses. For example, in 1975 NHA financed dwelling starts in Newfoundland increased by 118 percent over the previous years value and by 130 percent over the average for the previous five years.

Combined, the number of changes that have occurred without corresponding changes in some of the building details, have brought about an increase in moisture problems. Such moisture problems can be broadly divided into two categories:

- Problems which affect the part of the enclosure on the room side of the vapour retarder* - in this case, condensation and persistently high relative humidities in poorly ventilated areas, such as corners and closets, may lead to decay of wall coverings and also to growth of mould and mildew. Here the "damage" may have aesthetic, psychological and health connotations.

- Problems on the cold side of the vapour retarder - in this case, condensation occurs in concealed spaces and may not become evident before substantial damage to framing members has occurred. It should be noted that moisture problems will only lead to "damage" if the wood remains at a high moisture content for a prolonged period of time under the right temperature conditions.

Each of the above will be discussed in later sections of this report.

---

* The term vapour retarder is considered preferable to vapour barrier in that the term barrier implies a material which is totally vapour impermeable.

2.0 AIRTIGHTNESS

Because airtight housing and associated problems are a new phenomenon, this section is a compendium of opinions, not always based on carefully conducted experiments or studies. Comments are primarily based on intuition and judgement from experience and observations. It is, however, considered worthwhile to include this discussion as many apparently unrelated items have a direct bearing on moisture problems in existing, new, and yet-to-be-retrofitted housing.

It is now believed that post-1947 housing experiences, under natural ventilation (interior pressures ranging from -10 Pa to 10 Pa), an average of 0.3 ac/h. Moreover, a considerable amount of variation in the ventilation rate can be expected. Depending upon the season, wind velocity, the house type and method of heating, higher rates of ventilation are expected in houses with flued heating types. This is particularly so during the winter, when furnaces are in operation, or during periods of high wind velocities. With presently available materials and techniques, it is believed that natural ventilation rates, which are already low, can be further reduced by 30 to 50 percent by weatherizing - i.e. a 30 to 50 percent reduction of 0.3 ac/h. Although pressurization tests were not undertaken as part of this project, problem housing in Newfoundland and other locations (continuous air vapour barriers, row housing, electrically heated, and maintained with high internal humidity) are expected to exhibit low rates of air change.

It is recommended however, by Lawrence Berkley Laboratories and ASHRAE (Std. 62-1981, "Ventilation for Acceptable Air Quality") that 0.5 ac/h be provided to maintain acceptable indoor pollutant levels.

As a consequence of the above considerations, and judgements by coroner's juries implicating airtight housing in cases of carbon monoxide poisoning and ureaformaldehyde foam problems, the Ontario

Ministry of Municipal Affairs and Housing will, in the new Ontario Building Code, recommend forced air ventilation rates for flueless housing of 0.3 ac/h. This will be specified to be by fan ventilation. Since the above will be additional to existing natural ventilation, it will provide a total ventilation rate of at least 0.5 ac/h.

If such code changes are accepted across Canada, new housing, except for that in exceptional areas such as Newfoundland, will probably be adequately ventilated to control potential moisture induced problems caused by high relative humidity levels in the home. Local climate is important, and in some parts of Canada humidification for comfort may need to be provided.

The energy cost implications of the extra ventilation are significant. It has been variously estimated that the increased ventilation will add from $200.00 to $400.00 to the annual heating cost of the average home. (Details of additional heating costs expected as a result of ventilation are contained in "Applicable Moisture Reduction Techniques for Newfoundland by Marshall Macklin Monaghan for CMHC, File 176-4-25, Part 3.) It has been estimated that an air-to-air heat exchanger system and improved airtightness for new housing can be provided for $1 900 to $2 500. In order to respond to expected consumer demand for lower heating costs, it would be reasonable to expect industry to respond quickly to provide air-to-air heat exchangers and increase the airtightness of housing.

If the above conditions are complied with, there will be double insurance against moisture damage to new housing. If other provinces adopt policies similar to the new Ontario Building Code, during transition years the combined forced and natural ventilation will provide sufficiently low relative humidity levels in the home to avoid condensation problems (except, possibly in Newfoundland). Later, improved airtightness detailing should virtually eliminate concealed condensation by closing leakage paths. Such airtight

housing is already routinely built by one builder in Winnipeg, Manitoba (Flair houses). Similar results were produced in Brampton, Ontario as a part of the Ontario Ministry of Energy low energy housing demonstration program. In these units, air barriers were provided by making the drywall continuous through partition walls and joist space assemblies.

Ventilation should not be considered the only available option to control moisture damage and minimize long term moisture problems in new housing. Passive solutions, which improve the ability of the building enclosure to cope with the forces imposed on it, are preferred over mechanical equipment. Mechanical ventilation may be too costly to operate or maintain, may be too noisy, and could fail.

For instance, the passive approach to moisture control, which attempts to build safeguards into the building, has been adopted by the Foundations and Drainage Subcommittee of the HUDAC Technical Research Committee.[21)]

In close co-operation with the manufacturing and housing industries, CMHC and other regulatory and research organizations have also developed and promoted methods to minimize heat loss, water leakage and moisture problems.

In the case of existing housing, the range of cost effective methods for reducing moisture build-up in housing is substantially curtailed over those for new housing. It is nevertheless essential to be aware of air quality in the selection of possible solutions for the control of moisture damage. This implies that, regardless of the system selected for moisture control, some form of ventilation will need to be provided.

3.0 MOULD AND MILDEW ON ROOM-SIDE ENCLOSURE SURFACES

3.1 General

This chapter deals with the part of the building enclosure located on the room-side of the vapour retarder. The influence of the part of the enclosure on the outside of the vapour retarder will only be considered as far as it affects room-side surface temperature. Since the vapour retarder forms a physical barrier between the inside and the outside, moisture damage to the room-side does not necessarily indicate that the wall itself is in distress. Conversely, a wall where structural damage has occurred as a result of moisture need not experience visible room-side problems.

"The occurrence of visible condensation on the room-side surfaces of windows, walls, floors and ceilings depends upon the combination of the relative humidity and the extent of cooling produced at the surface in question".[4)]

Room-side surface temperature is, therefore, of interest in that it affects comfort as well as dust marking or "thermal dusting" and mould and mildew formation on wall surfaces.

"Thermal dusting" is apparently caused by relatively small variations in surface temperature at thermal bridge locatons or caused convection within wall cavities.[5)] It has been suggested that a temperature difference of from 3 to 5°F (1.5 to 3.0°C) on the wall surface may produce noticeable dust patterns.[6)]

Mould and mildew formation on walls, caused by the creation of an environment favourable for its growth, is more serious since, in addition to aesthetic considerations, there is also concern about psychological and health aspects.[7)]

When dealing with the growth or survival of mould and mildew forming organisms, factors such as surface temperature, availability of moisture and the chemical nature of the surface are all important factors.

3.2 Reasons for Mould and Mildew Formation

It is not known whether actual condensation, or merely a more or less sustained high relative humidity in the air film next to the exterior wall or attic ceiling, is a prerequisite for mould and mildew growth. What is known is that the combination of high room-side relative humidity and lower envelope surface temperature are both critical factors. Envelope surface temperature depends on factors such as indoor and outdoor temperature, thermal resistance of the enclosure, air leakage through the envelope, convection within the wall system, air currents acting on the inside and outside envelope surfaces, etc. Room-side relative humidity depends, to a large degree, on occupant lifestyle, moisture released by the building itself and air change rate.

It is, therefore, necessary to establish the factor most effective in controlling condensation, be it a change in envelope surface temperature or a change in indoor relative humidity. Curves for different outdoor temperatures, relating wall surface temperature to the thermal resistance of the wall were plotted and are shown in Figure 3.1. In order to simplify the curves, indoor temperature (taken here to be 20°C) and the surface film resistance (taken to be 0.011 $m^2.°/W$) have been assumed fixed.* For analysis purposes, similar sets of curves were also plotted for indoor temperatures of 10°C and 23°C, representing closet and ground floor temperatures respectively. These curves were used in analysis, but are not presented here.

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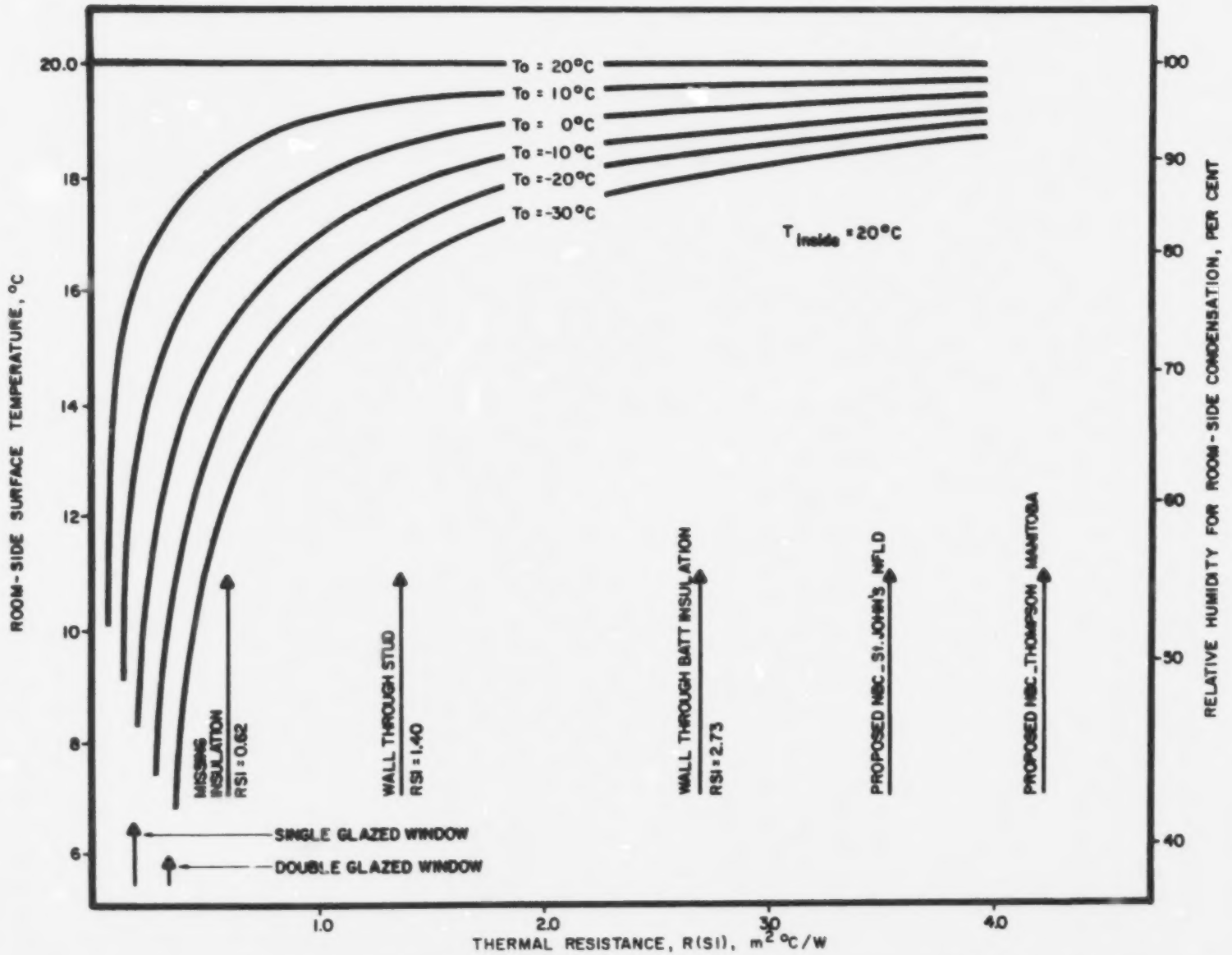
* The resistance to heat flow is, therefore, measured in watts per square metre per degree Celsius temperature difference across the material thickness.


ROOM-SIDE SURFACE TEMPERATURE, °C
RELATIVE HUMIDITY FOR ROOM-SIDE CONDENSATION, PER CENT
THERMAL RESISTANCE, R(SI), m² °C/W
To = 20°C
To = 10°C
To = 0°C
To = -10°C
To = -20°C
To = -30°C
T inside = 20°C
MISSING INSULATION RSI = 0.62
WALL THROUGH STUD RSI = 1.40
WALL THROUGH BATT INSULATION RSI = 2.73
PROPOSED NBC - ST. JOHN'S, NFLD
PROPOSED NBC - THOMPSON, MANITOBA
SINGLE GLAZED WINDOW
DOUBLE GLAZED WINDOW

A PLOT OF THERMAL RESISTANCE AGAINST ROOM-SIDE SURFACE TEMPERATURE OR ROOM-SIDE RELATIVE HUMIDITY LEADING TO CONDENSATION ON WALLS

FIG. 3.1

To determine the wall thermal resistance at the point of condensation, for a predetermined room relative humidity and outdoor temperature, a horizontal line from the relative humidity value on the right vertical axis is drawn to intersect the curve for the selected outdoor temperature. The point of intersection will then determine the desired thermal resistance value. For reference purposes, thermal resistance values for windows and various parts of "standard" 2 in. x 4 in. (38 mm x 89 mm) stud walls, have been included.

The wall curves in Figure 3.1 show that, the likelihood of condensation on a given surface also increases as the thermal resistance of the wall and outdoor temperature decrease and the indoor relative humidity increases. These curves also show that, in the low R-value range, a small increase in thermal resistance will have a large effect on reducing potential condensation. At the higher R-values the same incremental increase in R-value will have only a very small effect on condensation potential. In this case, the thermal resistance of the air film adjacent to the inside wall surface decreases as an important component of the total resistance of the wall system.

At high relative humidity levels (80%), there is complete agreement between field observations and the theoretical discussion summarized in Figure 3.1 concerning the onset of condensation. Although such high levels of relative humidity are virtually impossible to sustain in open spaces during cold weather, extremely high RH levels are possible in areas where localized cooling takes place. These locations are found in closets, under carpets, behind curtains, clothing and wall hangings against exterior walls. At these high relative humidity levels, increases to the thermal resistance of the wall will not prevent condensation. Localized cooling due to unintentional insulation on the warm side of the wall surface must, therefore, be avoided.

However, at the 50 - 70% RH levels, a major discrepancy between field observation and the theory as summarized in Figure 3.1 is noted. For example, condensation on a wall surface with missing

insulation is not shown to start before the outdoor temperature falls below -30°C and the indoor relative humidity exceeds 65 percent. Similarly, mould and mildew should not take place at a stud location until the indoor relative humidity exceeds about 75 percent. Such condensation was, however, common in problem buildings (at higher outdoor temperatures and lower indoor relative humidities). Field observations, therfore, suggest that, in certain spots in the wall, air movement has resulted in inside surface temperatures lower than would normally be expected.

Laboratory measurements have demonstrated that, three-dimensional heat flow and wall cavity convection resulting from careless installation of insulation, can lead to substantially lower surface temperatures than those predicted by the theoretical parallel heat path modelling, used to derive Figure 3.1.[6, 8, 9] The observed discrepancies are, however, still too large. It is suspected that infiltrating cold air or cold air taking a "short cut" through the wall construction and although not penetrating the air/vapour retarder, is by-passing the siding sheathing and insulation complex as well as the studs. Insofar as the room side surface temperatures are concerned, at localized spaces the envelope is only composed of the air/vapour barrier and dry-wall.

Poor detailing and workmanship found during the field observations, strongly support suspected cooling of interior surfaces by forced convection within wall systems.

3.3 Effect of Climate on Mould and Mildew Growth

Mould and mildew was found in all areas which experience extreme climate. The major contributing factors are:*

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* Details supporting these comments can be found in: "Moisture Induced Problems in NHA Housing. Analysis of Field Survey Results and Projection of Future Problems" - Part 1 of Contract 176-4-25 by Marshall Macklin Monaghan Limited.

- Low outdoor temperature, such as in Thompson, Manitoba;

- High indoor relative humidity, which in turn arises from the combination of high outdoor vapour pressures and high indoor moisture content (Newfoundland, the Maritimes and B.C. coastal regions are, therefore, affected);

- Exposure to winds. This study has shown a strong correlation between first floor mildew problems and exposure to strong winds. Here wind and stack action combine to promote air infiltration and thereby cooling of interior surfaces.

3.4 Wall Conditions Favourable for Mould and Mildew Growth Caused by Low Indoor Temperatures

The vapour pressure within a dwelling depends on the outside relative humidity, the rate of moisture gain within the enclosure and the number of air changes experienced. With reasonable internal ventilation, similar vapour pressures can be expected within the various parts of a dwelling. This does not apply to temperature and relative humidities, as these can vary with time, from room to room, and with variations in heat input and heat loss.

The moisture content of the air in a house will be fairly constant at any one point in time. In the bedrooms, where temperatures are usually lower, the RH will be higher than the RH on a warmer first floor.

If, for example, the temperature on the lower floor of a two storey house is 23°C and the relative humidity is 50%, the upstairs, with an 18°C temperature, would be expected to have a relative humidity of just below 70 percent. A greater incidence of mildew formation on the second floor was indeed observed in the survey.*

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* Details supporting these comments can be found in: "Moisture Induced Problems in NHA Housing. Analysis of Field Survey Results and Projection of Future Problems" - by Marshall Macklin Monaghan for CMHC 176-4-25. (Part 1)

Relative humidities would be even higher inside a closet adjacent to an exterior wall. The worst case is the cantilevered closet, where heat gain is only experienced through the closet door and heat is lost to the outside through the three exterior closet walls,* the floor and the ceiling. If indoor air at 23°C and a relative humidity of 50 percent is cooled to 12°C in a closet, the relative humidity in the closet would reach 100 percent.

Conditions in a closet are even worse if clothing resting against the closet wall and items stored on the closet floor interfere with air circulation and act as additional insulation. This will further lower the inside wall temperature. Freezing of clothing to closet and hallway walls, and the formation of mildew behind such clothing, was reported in Thompson, Manitoba. In Newfoundland, mould formation in clothing has been reported in cantilevered closets.

3.5 Recommendations for Existing Problems

As seen in Figure 3.1, only a very small amount of insulation is needed to increase the wall temperature to a point where condensation, for reasonable to high relative humidities, should not occur.** It is therefore important to impede the movement of cold outside air in the wall system. As a retrofit action, this will, however, require the removal of the siding to ensure the installation of a continuous exterior air barrier.

Probably the simplest and least costly measure would involve placing a relatively thin layer of insulation over the room side face of the wall at the point where condensation is occurring. In most cases, only an area 200 mm beyond a particular corner would need to be covered. While this will change the appearance of the interior, it can be considered as a cornice for the wall ceiling junction, and may even enhance the appearance of the wall.

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* These walls are non-structural.

** It takes only a small increase in R value to "move" along the curve in Figure 3.1 from the vertical to the horizontal portion.

The insulating corner pieces could be prefinished with a fire protective layer and fastened with an adhesive. This adhesive would also provide the essential airtight seal between the wall and the insulation.

In less severe cases, the painting of affected surfaces with a non-absorbent oil paint may be effective. If water is prevented from being absorbed by the dry-wall, a moisture reservoir which would otherwise supply moisture during dry conditions, would be eliminated.

Where siding has to be replaced, it would be preferable to add insulating sheathing in conjunction with a vapour permeable but airtight air barrier, such as a spunbonded olefin film* or similar material. This approach will be dealt with in greater detail in Section 6. In most cases**, the insulated sheathing could be applied directly over the existing sheathing. However, care will need to be taken with the attachment detailing for the siding.

Because of high relative humidity conditions, closets with walls to the exterior may not respond to increasing the insulation on walls. It is, therefore, proposed that an attempt be made to increase closet ventilation. Although not yet tested in practice, this could be accomplished by creating openings on the top and the bottom of the closet door. Openings would provide a means for entry and exit of room air. A sheet of rigid board, such as masonite, could then be placed on furring strips against the exterior wall and the floor, creating a vented wall cavity, open to the warm room air. Continuous circulation through the cavity would be set up, bringing warm room air into the closet. The rigid board would perform yet another function, as it would prevent clothing and items stored against the closet wall and on the floor, from coming in contact with the cold surfaces.

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* An airtight but vapour permeable film.

** Although this area is currently being researched, it is thought that under most climatic conditions this approach is acceptable even though plywood sheathing with an externally applied insulating sheathing can create an effective vapour barrier. In very cold climates, however, moisture accumulation within the wall cavity could become excessive.

4.0 WINDOW CONDENSATION

4.1 General

Condensation on inside window surfaces[11] is a common winter complaint in most of Canada, especially in buildings in which some attempt is made at humidification. Window condensation not only reduces visibility and is psychologically irritating, but it can lead to severe damage by wetting of surrounding construction. Rotting of framing below windows could also occur if the condensate can bypass the polyethylene vapour barrier and gain access to the interior of the wall.

Since the publication of the above 1960 Canadian Building Digest, window condensation has become more of a problem, with increased indoor humidity as a result of decreasing ventilation levels. Some degree of disfigurement or staining of window frames due to the growth of mould was commonly observed during our field investigations and, in extreme cases, mould blocking window frame drainage openings was noted. In cold regions, the draining of condensate has ruined plaster below window sills and floor coverings adjacent to the window. Corrosion of wall connections for baseboard heaters has also been reported. Cases of condensate running into walls and rotting out framing members or leading to freeze-thaw damage of masonry materials have been reported.

4.2 Control of Window Condensation

Triple glazing, thermal breaks in aluminum window frames and forced ventilation over inner window surfaces are but a few examples of measures which can lead to higher window inside surface temperatures and, therefore, increased tolerability to high inside humidities. However, the replacement of poorly performing windows is not only costly, but possibly ill-advised. It is, rather, the relative humidity which should be reduced to more reasonable levels.

Some of the measures which have been taken to minimize damage from window condensation have included replacing damaged dry wall below windows with plywood, and the replacement of carpeting below windows with linoleum, from which condensate can be periodically mopped up. Although this does not reduce condensation, steps have been taken to eliminate further damage.

5. ATTIC CONDENSATION

5.1 General

In older housing the uninsulated attic seldom experiences moisture problems despite the absence of a ceiling vapour barrier or attempts to make attic floors airtight. Yet, the modern, well-insulated attic with vapour barrier, even if properly installed, often experiences significant moisture problems if proper attention is not paid to attic ventilation. It is impotant to note that where attic problems were noted in our field investigation, inadequate attic ventilation was also observed. The least serious problem manifests itself in modest water leakage through the ceiling, after an extended period of frost with minimal solar gain. At the other extreme are other cases or events such as:*

- o roof joists, truss members or sheathing rot, to a point where structural collapse is possible;
- o serious deterioration of interior room finishes, due to leakage of attic water;
- o corrosion of attic electrical fittings and truss plates;
- o decrease of thermal resistance of insulation, due to excessive moisture;
- o roof trusses that bow, to the extent that the ceiling is pulled away from interior partition walls.

In modern housing, the amount of moisture entering the attic space through the ceiling, has increased because of generally higher inside relative humidities and, in the case of electrically heated housing, the lowering of the neutral pressure plane.

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* Some, but not all of these problems were observed in the field by the consultant on this project.

Land and building cost considerations favouring two to three storey row housing over single storey bungalows, have further increased the "stack pressure" against the top floor ceiling. Also, for the same overall floor area, the multi-storey building has a smaller roof area, leading to a higher condition of moisture per unit ceiling area. In row house units, soffit vents are limited to the front and back walls, and should wind occur parallel to the building, wind induced pressure differences between the opposite soffits may disappear, interfering significantly with attic ventilation. The reduction of the number of exterior walls also reduces the number of parallel paths for air leakage.

Whereas modern trends have favoured increased entry of moisture into the attic or roof space, the increase in the ceiling thermal resistance has lowered the temperature in the attic space above the insulation. This has seriously reduced the ability of ventilation air in the attic space to cope with moisture.

5.2 Effect of Climate Considerations on Attic Condensation

There are two extreme weather conditions operating in the field which affect attic condensation in completely different ways. Of these two, a prolonged but relatively mild heating season, when coupled with high outside relative humidity and a lack of solar heating (which represents conditions in Newfoundland), is the more severe. In this weather regime, the combination of high moisture contents in wood and above-freezing temperatures, provides an ideal environment for mould, mildew and rotting.

The other extreme is a climate with a very cold heating season, high solar gain throughout the year and a rapid drying season. These conditions are prevalent in northern areas. Here, moisture escaping into the attic freezes on sheathing and truss members, and thaws out during the spring. This could result in leakage into the walls and the living space below. Rapid drying will, however, occur and, because conditions are either too cold or too dry, mould and mildew

should not develop. (Very little was found during our field investigations.) Rotting could occur but only if moisture is sealed in the attic or roof space, or leaks into wall cavities which are not well drained.

For in-between climatic conditions, attics, when reasonably ventilated, dry out relatively quickly. In one investigation in the Ottawa area, it was found that the top chord members of the roof trusses became wetted during the heating season. Maximum moisture content of 19 percent were reached in February, drying out quickly to 15 percent by March and 12 percent by May. At the same time, the bottom chord members, embedded in thermal insulation, remained at a constant and low moisture content throughout the year.[14] Unless extreme conditions are encountered, major problems should not be anticipated in the "moderate climate areas".

3 Control of Attic Condensation and Recommendations for Retrofit

Lack of ventilation in roof construction, either due to poor design or careless installation of insulation, will contribute to moisture damage in attics. Increasing ventilation alone may, however, not solve the problem. It has been suggested that significant ventilation rates are necessary to ensure removal of moisture from the attic space. However, when moisture holding capacity of the outside air is reduced, either due to low temperature or high relative humidity, high rates of ventilation may increase the condensation problem. High ventilation rates can also increase the problem by facilitating leakage of interior air into the attic space if the ceiling construction is not sufficiently airtight.[12]

It is broadly agreed that the transfer of water vapour from living space to the attic is almost entirely by air movement.[13] To solve the problem, an air barrier between the living space and the attic must be created. While decreasing the inside humidity will help, in addition to existing vapour barriers, the emphasis must be on the continuous air barrier.

Where attic space is accessible, attempts should be made to seal gaps in the air barrier, such as over the interior partition walls, over light fixtures and around plumbing vents and electrical penetrations. Existing vents should be cleared or new ones added. Where necessary, header air tightness at locations of exterior walls should also be improved.

In extreme cases, fan pressurization of the attic space could be considered to counteract the stack pressure. This is, however, not without its own problems. It is conceivable that a complete reversal inflow could cool areas to a point where condensation and mildew formation becomes a problem. As an alternative, wind scoops facing prevailing winds, and for row housing parallel to prevailing winds, could be considered to increase attic pressure and overall attic ventilation.

In the case of retrofit to houses, moisture conditions must be considered before undertaking thermal retrofitting. There is much room for the development of materials and construction details to deal with the various climatic conditions and roof types. For example, the use of spunbonded olefin film or similar material applied over the top surface joist, to form a vapour permeable but airtight membrane, needs to be evaluated. Another approach, which should be investigated, is the sealing of partition wall leakage paths, by cutting through the dry wall/lath and plaster at the top plate level and caulking and sealing the crack. As this work is done from inside the house, it would be suitable for cases where the attic or roof space is not accessible.

6.0 MOISTURE PROBLEMS IN WALL CAVITIES AND SOFFIT AREAS

6.1 General

This section deals with condensation in the wall cavity between the siding and the air-vapour barrier, as well as, condensation in the soffit area.

With construction practices which allow for reduced air change rates (but without controlled ventilation), changes to flueless heating, and reductions in average building sizes, increases in cases of moisture damage to walls should be expected. Generally, most of the moisture will be concentrated in areas where a small number of flaws exist in the continuous polyethylene vapour barrier (near electrical outlets or at details where the barrier continuity is broken).

As in the case of attic condensation, it is generally accepted that water vapour diffusion from the interior is an insignificant component of moisture entry into the wall. It is air leakage which is responsible for the transport of most of the water through gaps in the air-vapour barrier. Moisture in the wall cavity could be further increased by condensed water from the attic and from windows, as well as by rain water penetrating through detailing or installation faults in the exterior "rain screen".*

It is virtually impossible to totally eliminate condensation within a wall system, and it is expected that most houses in Canada experience periodic condensation within the wall cavity. There is usually, however, sufficient moisture storage capacity in the cavity to absorb this water without damage. It is only when wood moisture contents in excess of about 20-25 percent persist for prolonged periods of time, at above-freezing temperatures, that rot and possible structural damage can occur.

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* Siding or other exterior materials.

6.2 Extent of Wall Condensation Damage Observed

Unfortunately, damage due to concealed condensation is itself concealed. Moisture damage within the wall cavity, observed during the study, was very limited and similar to observations by others.[15] In this study five problem houses were selected for further detailed investigation. These units experienced all or some of the following:

- o high indoor relative humidities;
- o excessive window condensation;
- o mould and mildew on interior wall surfaces;
- o mould and mildew in attics;
- o high siding and framing member moisture readings.

When walls were opened, localized rotting, traced to a fault in the vapour barrier, was only found in one of the five buildings. In others, high moisture contents of framing members and water markings indicated that condensation had occurred, but not at optimum temperatures or for sufficiently long periods of time to result in rotting.

Indications from the Part 1* of this project, suggest that the extent of rotting of wall framing members is not widespread. Theory and field investigations indicate that localized damage, especially in areas where moisture can move outward by air movement, can be expected to be present. It is not, however, anticipated to lead to sudden large-scale, nation-wide, structural collapse of housing units.

6.3 Moisture Dynamics in Wall Cavities

Movement of liquid water and water vapour in and out of the wall, and its storage within the wall, is a complex process. The general

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* Analysis of Field Survey Results and Projections of Future Problems. Marshall Macklin Monaghan, November, 1982. CMHC Contract 176-4-25 (Part 1).

understanding of the process is further confused by most research done to date using highly idealized models to predict heat, moisture and air flow. While these models may be valid under steady state conditions and in ideal circumstances, conditions in real structures are far from ideal. Moreover, single component effects cannot always be superimposed. Similarly, laboratory evaluations dealing with one variable at a time, such as the effect of moisture diffusion on wall moisture build-up, are of limited value as they ignore the effect of moisture transport by air leakage.

The results of research from such idealized models and tests are nevertheless useful, and indeed essential, in order to interpret field observations, predict the impact of proposed changes to the building enclosure and direct the program for future research.

6.3.1 - Transport of Moisture by Moving Air

Air movements through openings and throughout the wall cavity are caused by pressure differences. The instantaneous absolute pressure, at any one point in the building enclosure, will differ from the ambient barometric pressure primarily due to wind, stack effect and the heating and ventilating system action. The magnitude of these pressure differences will vary with time and location.

The enclosure of a building experiences pressure variations across the interior face and the exterior face, as well as within wall cavities themselves. Major deviations from local "average" pressure will occur under soffits and around corners. Where inside pressures equal those outside, the area is defined as the neutral pressure zone. Because the pressures on opposite faces of the enclosure are caused by different forces, the neutral pressure zone does not remain in the same location. The amount of air moving through a given opening in the air-vapour barrier will, therefore, vary with time. Infiltration can change to exfiltration, and vice versa, as the iocation of the neutral pressure plane changes.

A normally constructed vertical residential exterior wall is composed of various layers, each being penetrated by more or less randomly located openings. Most of these openings are, however, directly or indirectly interconnected. Movement of air within the wall system can, therefore, occur through openings in studs, cracks between studs, plates and framing members, or through passages between the siding and the sheathing.

Behaviour of air and moisture movement in a wall is a complex phenomenon and has been confused by labelling the sheet of polyethylene (which now replaces the vapour barriers attached to individual insulation batts), as the air/vapour barrier. It should be recognized that all parts of the enclosure offer varying resistances to air movement. It should also be recognized that there is no structural design reason for the air and vapour barrier being formed by a single component. There is also no preferred location for the air barrier. Each case has to be examined separately. Some material combinations are, however, essentially vapour impermiable and have inadvertently created a vapour barrier in the wrong place. Under certain climatic conditions, this situation has been claimed to lead to moisture damage. Particularly in Newfoundland, non-vented plywood sheathing when installed without a vented furring space in combination with some forms of horizontal siding, has resulted in cases of buckling and warping of the siding*. Localized rot of the sheathing material at penetrations of the polyethylene vapour barrier has also been noted.

6.3.2 - Condensation of Air-Borne Moisture

Passages allowing air movement exist in most building materials. Materials also have various moisture and heat storage capacities and abilities to conduct heat. Because of inside/outside temperature differences during the heating season, temperatures will, therefore,

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* As noted elsewhere in this report, siding problems were also noted in Newfoundland in conjunction with board sheathing.

vary from point to point within the wall. Consequently, when air moves through the passages within the wall cavity, it will absorb heat or give off heat as the case may be.

It should be noted that, if air velocities are high, the air and insulation temperature at any given spot along the leakage path is not equal to the average temperature away from the leaks. The insulation within the wall will prevent conduction of sufficient heat to warm the air to local values.

As it is heated, air experiences an increase in its moisture holding capacity. As it is cooled, capacity decreases and warm, moisture-laden air from the interior will deposit moisture in the wall cavity. Moving dry air can also absorb moisture condensed on earlier occasions if cool air enters the same cavity through flow reversal. (This will happen as the location of the neutral pressure zone changes.) If air velocities are high enough, no significant cooling or warming will take place within the wall and the majority of the temperature change will take place in a mixing zone at the exit of the crack that controls the air leakage.

Air movement through and within the wall can transport moisture from one part of the wall to another through the wall (either into or out of the building envelope) and to either face of the wall cavity.

This being the case, when one deals with the moisture balance in a building, moisture stored in walls can not be negiected. Infiltrating air can absorb substantial amounts of moisture from the wall, drying the wall in the process and providing moisture to the interior beyond that which would be expected from the outside air alone.

While there is a great deal of randomness to air movement in the wall, its cooling and heating and the amount of moisture present in the wall cavity, certain systematic trends exist. During the heating season, the temperature gradient in the wall will concentrate moisture on the coldest surface encountered. This is usually the exterior part of the wall cavity (sheathing and siding). In an air conditioned house, the reverse situation could exist during the summer.

Even without direct condensation, the relative humidity will be higher in colder parts of the wall cavity than in warmer parts. The amount of moisture deposited on a given surface and absorbed by the material forming the surface will, therefore, depend on the vapour pressure and the temperature. For a given vapour pressure within the wall cavity (the vapour pressure itself being dependent on such factors as the outside climate, the amount of moisture generated by the occupants, etc.), the dew point will eventually be reached as the temperature is lowered, allowing water to condense. Since the coldest surface in the wall cavity system is usually the inner face of the outer sheathing, once the rate of water condensation on the surface exceeds its ability to absorb moisture or transmit moisture by diffusion, free water will appear on the inner surface. From here it will run down, possibly saturating other materials. The amount of water condensing at a given location depends on the rate at which moisture can be supplied and on the length of time the surface is below the dew point.

The rate of condensation can be very high if an air current carrying humid air from the interior strikes cold sheathing. During our investigation, localized wetting and rotting was observed opposite an electrical outlet in a house in Newfoundland. Free water had been deposited on the sheathing directly opposite an electric outlet. In this location, there was a penetration of the vapour barrier, and enough water had run down to saturate the sole plate, header joist and sill plate. Since the heat of condensation given off by the water vapour was carried off rapidly through the single sheet of saturated combination sheathing and siding, the sheathing surface remained cold and condensation continued .

Sufficient quantities of water had run into the sole plate, header joists and sill plate assembly to cause extensive rotting. The wall studs adjacent to the leakage opening were, however, in a good condition in spite of moisture contents in the outer face having reached values of 40 percent. Apparently, sufficient drying had occurred during the summer to prevent the occurance of rot in the

joists. The joist assembly decay appeared to be localized and was not considered to be serious enough to lead to potential structural collapse.

6.4 Sheathing Materials and Their Effect on Condensation

6.4.1 - Traditional Sheathing Assemblies

Many traditional sheathings, such as sawn lumber, asphalt treated wood, fibre board, gypsum board, plywood and waferboard have performed well under reasonable circumstances. However, prolonged heating seasons and high interior moisture loadings, when coupled with driving rain, low solar gain and low permeability building paper and siding, can result in high sheathing moisture contents which, could lead to rotting*.

Detection of problem cases is relatively easy. An investigation is usually triggered by visual concerns such as buckling or staining of siding. Wood moisture meters can also be used to establish (more or less non-destructively) high moisture content cases. Such surveys should be carried out after several weeks of drying weather because high temporary* moisture contents in the sheathing during the heating season is not, necessarily, indicative of potential structural problems.

6.4.2 - Non-absorbent Insulating Sheathing

If non-absorbent insulated sheathing materials, such as extruded polystyrene foam, are used (instead of traditional sheathing materials), the inner face of the sheathing is expected to be substantially warmer than with most traditional sheathing materials.

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* Problems are not expected if the wall can dry out quickly in the spring.

As a consequence, the length of time the inside surface of the sheathing is below the dew point temperature will be substantially reduced. This would mean that the total amount of moisture that condenses on the warm side of the insulating sheathing could be substantially reduced. Moreover, the low heat capacity of polystyrene foam, combined with its high thermal resistance, will result in the heat of condensation being stored and the warm air itself locally warming the inside surface above the dew point. Condensation adjacent to the leakage opening is less likely to occur than in the case of traditional sheathing materials.

Theoretical considerations, backed by a substantial body of laboratory and field testing by a manufacturer, indicate that as far as concealed condensation is concerned, walls with insulating polystyrene sheathing experience fewer moisture problems than walls with traditional sheathing. There is also agreement that the overall thermal performance of the wall is enhanced if the joints between the insulating sheets are deliberately sealed. There is still, however, some concern about what happens to moisture "trapped" in the wall cavity. (Research in this area is not complete.)

Because of a lack of consistent research data, some concern has been expressed about the "dangers" associated with low permeability sheathing. (Extruded polystyrene sheathing would fall into this category). As a precaution against moisture becoming trapped between two moisture retarders, many inspectors insist that gaps be left between the insulating boards in order to provide ventilation.*

To control concealed condensation in the wall cavity as a result of air exfiltration, the important criterion is that the air barrier be continuous. Exfiltration air will shed part of its moisture when cooled

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* This requirement for ventilation is specifically identified in CMHC Technical Bulletin T3 1981-0727, Section 26, Sub-section 2.

below the dew point on its passage through the wall. Concealed condensation can, therefore, be prevented if the passage through which air is exfiltrating is sealed off. (If a vapour barrier is in place, the location of the air seal is not of importance.) A localized hole in the polyethylene vapour barrier (such as at an electrical outlet) is not critical if a separate, effective air barrier has been provided to seal off the passage.

There are, however, a number of considerations which favour the location of the air barrier on the outer face of the enclosure, namely:

- The exterior face of the enclosure forms a continuous surface without joist and surface penetrations and is therefore easier to make air tight. (This is especially the case with cantilevered floors or other construction details where vapour barriers are difficult to install.)

- Cold exterior air will be prevented from entering the wall system, eliminating one of the major causes for room-side wall condensation and, quite possibly, the associated mould and mildew problems.

- Heat loss will be reduced if forced convection by wind forces within the wall cavity is precluded.

The above factors suggest strongly that, for practical and energy reasons, a vapour permeable air barrier should be located on the outside face of the framing members.

Since field observations and research data are lacking, the required permability of the air barrier is difficult to determine. Presently available information indicates, however, that under given climatic conditions, where sheathing and siding assemblies are not separated by a vented furring space, they are not permeable enough and are likely to experience difficulties.

Further research is required in this area.

6.4.3 - Expanded Polystyrene and Glass Fibre Sheathing

Expanded polystyrene insulating sheathing is similar to the extruded polystyrene board, except that it has a higher moisture absorption capacity and high vapour permeability. Both factors are expected to improve drying by concentrating moisture in the sheathing material and permitting vapour to exit the system.

In the opinion of the author, glass fibre insulating sheathing, with a vapour permeable air barrier "facing", is believed to have a advantage over other forms of insulating sheathing. In case moisture does enter the wall cavity from inside the house, it will condense when it comes in contact with the "facing". When the "facing" is located on the cold side of the sheathing, it will promote condensation, acting as a dehumidifier as far as the framing members and the wall cavity are concerned. The cavity dew point temperature will, therefore, be established by the "facing" and, as a result, the relative humidity at the stud-sheathing interface will be low enough to prevent condensation in this location. This is the case because condensation will occur on the first continuous surface reached. In the case of glass fibre sheathing, this is the air barrier*.

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* Although this detail is not ideal, more guidance as to proper installation can not be given at this time. Further research is being done at the University of Toronto to determine optimum installation details for this material.

The drainage characteristics of glass fibre board and batt insulation combination wall systems are of particular advantage here. Lacking capillarity normal to the face of the board, a certain amount of water (or frost) will be stored only in the outer few millimetres of the insulation. When the area becomes saturated, water will drain along the outer face. A flashing provided at the bottom of the insulating sheathing can direct this water harmlessly to the outside.* Tape has also been developed to seal the joints between the boards. The top edges of the insulating sheathing boards should also be sealed. The bottom edge should be left untaped to permit drainage.**

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* Siding installation details will need to be altered to permit this drainage. It should be noted that if the condensate is stored as hoarfrost during a long cold spell, on melting the release of water can be sudden and extensive.

** Although this detail is not ideal, more guidance as to proper installation can not be given at this time. Further research is being done at the University of Toronto to determine optimum installation details for this material.

6.5 Cantilevers, Joist Assemblies and Partition Walls

Moisture related problems have been observed in the field in areas with difficult architectural details. Cantilevers, joist spaces and butting partition walls often exhibit moisture problems since construction details are difficult and the traditional air-vapour barrier has not been made airtight.

When the soffit of a cantilevered second floor of a Newfoundland house was investigated, the following was observed:

- A "drip", which would shed the water film, and keep it from running down the wall was not provided. Driving rain could, therefore, continue along the bottom of the plywood sheet forming the soffit.

- No attempt had been made to provide an air seal. External air was able to enter the joist space, drawing rain water with it.

- The insulation batts which were meant to be bent up to cover the header joist were poorly installed and did not cover the soffit.

- The insulating batts were provided with asphalt-impregnated kraft paper vapour barriers. About half of the batts had the vapour barriers facing the wrong way, indicating careless installation, lack of proper inspection, or lack of knowledge on the part of the installers.

Whereas careless workmanship and inadequate inspection can be blamed for some of these faults, the basic design detailing was poor, making it virtually impossible to provide a continuous air barrier and eliminate entry of rain water. The potential problem is compounded by the fact that most of those houses are electrically heated and have, therefore, no flue. As a result, the neutral pressure plane is lowered, leading to increased exfiltration of moist inside air.

6.6 Wall Condensation and Decay

6.6.1 - The Effect of Climate

Broadly speaking, both climate and occupant created moisture, determine the likelihood of the occurrance of high wall moisture contents and the nature and extent of problems caused by it.

Two climatic extremes exist in Canada. Newfoundland has a relatively moderate (but below freezing) temperature during the heating season, but little sunshine and high frequency of rainfall and driving rain. Thompson, Manitoba, has very low winter temperatures but no rain and considerable solar gain. Both situations could lead to high water accumulation in walls where construction details or faults in the vapour barrier permit entry of water vapour.

Problems are possible in Newfoundland. At areas of vapour barrier penetration or in conjunction with "poor" details, wood frame moisture readings taken on March 15, 1982, in St. John's, Newfoundland were found to be in a range where wood rot could occur. Severe localized rotting was found near electrical outlets in one problem building. Although the extent of damage is not known, interviews with CMHC inspectors confirmed that localized rotting had been found on other occasions in the area where walls had been opened. According to the CMHC chief inspector in Newfoundland, removal of siding has revealed extensive moisture damage to sheathing. Board sheathing, which is quite common in this area, was also affected, suggesting that in this particular climate region, if positive pressure exists in the house and inside moist air can exfiltrate into the wall system, air and vapour permeable sheathing is not necessarily immune to decay.

In Thompson, however, although water markings were observed on the interior surfaces of the sheathing, rotting, mildew or water damage was not found on the sheathing materials or framing members.

In the cold climatic regions, wall temperatures are too low during the winter to support the micro organisms responsible for decay. Once the walls thaw out, they also dry rapidly to bring wood moisture contents below the critical level. Hence, rotting does not become a problem unless a vapour retarder is located in the wrong place, thereby preventing the escape of moisture.

6.6.2 - Recommendations for Problem Housing

Measures to reduce indoor relative humidity should be taken, since these will significantly reduce the amount of moisture available for condensation in walls and attics. Measures which promote drying of the exterior face of the sheathing, or raise the temperature of the room-side face of the sheathing, will also reduce wall condensation. The extent of cost-effective corrective measures will vary for each region (meso-climate and construction practices). It is however, expected that simple, typical, cost-effective measures can be developed for each of the major climatic regions.

A major source of air leakage from the inside, into the wall cavity, can be reduced for a very modest expenditure. For example, placement of foam gaskets under electrical outlet cover plates takes very little time and a small capital expenditure. This action alone would remove a source of concentrated moisture movement into stud cavities. (The sill plate and header joist rot found in one of the Newfoundland houses investigated could have been avoided by these easily installed foam gaskets). A more extensive room-side and upper wall header caulking program may be justified for high moisture level housing. Although costly, this is still judged to be cost effective given the potential capital cost impact of not sealing.

Where siding has to be removed to correct siding problems, it is strongly recommended that insulating sheathing and an exterior air barrier also be installed. Energy conservation alone would fully justify the addition of the insulating sheathing and air-barrier. This

type of barrier would eliminate mould and mildew, within-wall condensation and the supply of interior moisture to siding. As detailed in Section 7, siding should be reinstalled on furring strips.

6.6.3 - Recommendations for New Housing

In most parts of Canada, traditional 2 in. x 4 in. (38 mm x 89 mm) insulated stud walls with conventional sheathing do not provide enough thermal resistance to meet the proposed new R-value requirements of "Measures for Energy Conservation in New Buildings" as well as in some provincial codes.

If 2 in. x 6 in. (38 mm x 140 mm) studs are used to meet the energy requirements, many of the conditions noted for the 2 in. x 4 in. (38 mm x 140 mm) wall could become more severe, unless indoor humidities are controlled and air leakage through the air barrier is reduced.

- o When friction fit batt insulation is installed, a vertical continuous air cavity tends to form along the intersection of stud sides and the sheathing. This promotes convective currents in stud spaces, reducing the thermal efficiency of the wall assembly.

Advantages of 2 in. x 4 in. (38 mm x 89 mm) walls with insulating sheathing are:

- o Stud thermal bridges will be blocked by insulating sheathing, reducing heat losses substantially and reducing the danger of room-side mould and mildew growth. (See Section 3.0)

- o Partition wall and joist assembly insulation, and vapour permiable air barrier installation, becomes simple and straight forward because the air barrier is installed on the outside.

- o Exterior basements insulation can be continued across first floor headers.

In the author's opinion, if industry adapts insulating sheathing while retaining the 2 in. x 4 in. (38 mm x 89 mm) framing, wall condensation problems should be virtually eliminated.

The technical arguments for insulating sheathing materials seem, to the author, to be sufficient to warrant highlighting its use and advantages in the various building codes. It should, however, be recognized that insulating sheathing materials may not meet the structural requirements of some buildings.

In addition, in new housing, if a minimum mechanical air change rate of 0.3 ac/h becomes mandatory, the associated decrease in inside relative humidity, when coupled with an effective air barrier to reduce air infiltrating from the outside, is expected to eliminate future wall moisture problems.

6.6.4 - Recommendations for Retrofit Housing

Moisture problems in retrofit attics are discussed in the other parts of this study.* The literature survey also identified a discussion on problems with retrofit walls. For example, a study in the United States[15], involving 39 houses with wall cavity retrofit insulation in six climatic regions, did not show wall component problems. It was also found[15] that the moisture content of the insulation was not significantly different whether a vapour barrier was installed or not.

Laboratory and field studies of exterior retrofit, with extruded polystyrene foam insulation[16] showed, however, that the moisture contents of wood siding and sheathing were consistently lower where walls were externally retrofitted with low permeability extruded polystyrene insulated sheathing.

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* See "Analysis of the Field Survey Results and Projection of Future Problems" by Marshall Macklin Monaghan, November, 1982 - Part 1 CMHC Contract 176-4-25.

As vapour barriers were not included in these laboratory and field test walls, the full significance of this work is difficult to assess.

Similar conclusions were recorded in a much larger field study involving 96 homes in Portland, Oregon, of which 71 had retrofit insulation and 25 were uninsulated.[17] This study concluded that the addition of wall insulation, without a vapour barrier, does not cause moisture damage in existing homes with wood siding in a climate similar to that of Western Oregon. It is of interest to note that the average number of air changes at 50 Pa was 16.2 ac/h (ranging from 5.4 to 37.5).

7.0 SIDING

7.1 General

There is, currently, considerable debate about the cause(s) of siding and sheathing problems. Problems are thought to be caused by internally generated moisture. The measures to be taken to correct current and avoid future problems are, however, difficult to determine. An attempt is made here to examine the various forces at play, and assess their effects on the siding, building paper and sheathing complex. Such an analysis is necessarily subjective, with potentially controversial conclusions.

7.2 Assumptions

With respect to the supply of interior moisture to the sheathing, it is expected that air exfiltration is the dominant moisture source, with the polyethylene sheet vapour barrier assumed to be bypassed because of holes at electrical outlets or other installation faults. With this action, we have concluded that the vapour pressure in the stud cavity is equal to the vapour pressure inside the building. While this assumption may over-estimate the vapour pressure in the cavity, the error is on the conservative side. It is believed to be a substantially smaller error than that produced when it is assumed that moisture is supplied to the wall cavity by diffusion only. The latter would greatly under-estimate the supply of moisture to the wall cavity. In the case of theoretical failure analysis, the diffusion condition is not of interest, since a structure with an effective air/vapour barrier will not experience critical conditions.

Acceptance of the foregoing hypothesis means that, in cases where air exfiltration into the wall cavity takes place, steady-state moisture diffusion analyses do not apply, when considering the supply of moisture to the room side face of the sheathing. Where glass fibre insulation with a water vapour permeability close to that of free air is

used in the stud cavity, the vapour pressure within the cavity can be considered to be constant. The vapour pressure within the wall cavity will now be between two extremes: on the lower end it will be determined by the dew point temperature of the coldest surface in the cavity; on the higher end of the scale it will be equal to the interior vapour pressure. The actual value will be determined by the difference between the rates of supply of moisture from the room-side and its removal by condensation.

Through the sheathing (from the first condensing surface - inside of sheathing - outward) approximate steady-state moisture diffusion models apply.

The second assumption made here is that, if liquid water from exterior sources does come in contact with the building paper, capillary forces will draw this water into the building paper and the sheathing. This flow will, of course, only occur if the capillaries of the building paper and the sheathing are not already saturated from interior sources.

7.3 Moisture from Interior Sources

In walls, which with the exception of cavity insulation are otherwise identical, the contribution to the total thermal resistance provided by the outside air film, siding, sheathing paper and sheathing of the uninsulated wall (no cavity insulation) is greater than that of the insulated wall. The room-side sheathing surface temperature will, therefore, be higher, as will be the temperature drop across the sheathing. Condensation on the inside surface of the sheathing for an uninsulated wall will, consequently, occur at higher vapour pressures than for an insulated wall. For the same history of indoor and outdoor temperature variations and indoor relative humidities, less condensation will be experienced in walls which are not insulated.

In view of the above, higher moisture contents in the sheathing and siding can be expected where walls are insulated. Another way of looking at this is to say that uninsulated walls could tolerate a lower permeance sheathing, building paper, or siding complex before moisture problems occurred. With the overall increase in indoor vapour pressure experienced in post-1975, tighter, electrically heated housing, if moisture can enter the wall cavity, higher moisture contents in the siding and the sheathing should be expected for insulated walls. (An insulated wall can, however, be made to perform like the uninsulated wall, as far as the rate of condensation on the sheathing is concerned, by using insulated sheathing.)

The above arguments are in agreement with observations. For example, one form of reconstituted wood siding* has been marketed in Newfoundland for more than twelve years. This siding began to experience moisture problems in the mid-seventies, when indoor vapour pressures experienced an increase, due to a higher predominance of flueless heating and more airtight construction practices.

The movement and accumulation of interior moisture in the siding in an insulated wall can, nevertheless, be controlled by separating the siding from the sheathing by means of a vented cavity. While the amount of condensation may increase marginally due to the reduction of the insulation provided by the siding, the removal of the resistance to vapour flow provided by the siding is expected to more than offset this. Drying of the sheathing is, therefore, expected if the two components are separated. With respect to the siding, interior moisture can now no longer reach it. Conditions for the siding will, therefore, also have improved.

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* Without any significant change in the manufacturing process.

A more important contribution to siding and sheathing drying is expected from heating by solar gain. The space created between the sheathing and siding will be heated by solar energy. This, in turn, will raise the vapour pressure of the moisture in the siding as well as in the sheathing paper and the sheathing, and enhance drying. Exchange of moisture between the siding-sheathing materials and this outer cavity will be further enhanced because of the increased moisture-holding capacity of the warmed cavity air. If openings to the outside air are provided at the top and the bottom of the cavity, convective currents will remove the moisture supplied to the air in the cavity and will provide drainage.

Venting the cavity between the sheathing and siding will reduce the amount of warming experienced due to solar gain but could create a situation where warm moist air enters the attic space through the soffits. More research on proper construction detailing is required in this area.

Painting the siding in a darker colour will also increase solar gain. The DOW Chemical Company reports 17 to 22°C higher siding temperatures during peak periods on the west wall where darker coloured finishes are used.* This would further promote the drying of the siding and sheathing complex when an exterior vented cavity is provided. Without venting at the furring space, however, the moisture would be driven back into the stud cavity.

7.4 Moisture from Exterior Sources

Most building materials will absorb moisture from the ambient air. Wood-based products have a particularly large affinity for moisture. The moisture content of wood will increase with an increase in the ambient relative humidity and, in an environment with a fixed vapour pressure, the moisture content will increase with decreasing temperature. Associated with increased moisture content are swelling

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* Unpublished reports.

and decreased thermal resistance. Cross-grain swelling is larger in comparison to parallel grain swelling. In reconstituted wood products siding with random fibre orientation, swelling in the length direction is greater than for lumber siding. When restraint to longitudinal swelling is provided, buckling may result.*

Cases where buckling of reconstituted wood fibre siding has occurred relatively soon after installation, illustrate swelling of the material as a result of absorption of ambient moisture (coupled with installation practices which restricts longitudinal expansion).

Such problems can be avoided as follows (singly or in combination):

- Reduce the basic swelling characteristics of the material by changing the properties of the product. Manufacturers have undertaken research and, although practical limits appear to have been reached, further research should continue.

- Pre-condition the product (as per manufacturers' installation instructions) so that it is as close as possible to equilibrium with the ambient moisture before installation.

- Use attachment systems which allow some longitudinal dimensional change.

- Careful attention should be paid to manufacturers' installation instructions.

A second source of exterior moisture is rain water which, under driving rain conditions, may penetrate the siding and come into contact with the sheathing paper. Although manufacturers' installation instructions address this problem, if contrary to installation instructions, lapped areas are tightly fitting, rain wetting

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* It should, however, be noted that this is an appearance problem only that the elimination of swelling or buckling does not mean that other wall moisture problems may not be present.

of the backs of siding elements can also occur by capillarity. (Unless the back faces are treated with a moisture resistent film, siding elements will absorb some of this water.)

When siding is in direct contact with the sheathing paper, a poorly vented outer cavity will result. Saturated siding and sheathing paper will maintain the cavity air in a saturated condition. High solar gain in the wall will now raise the vapour pressure in the siding and the space behind the siding, forcing siding moisture into the sheathing. To overcome these problems the following factors have to be considered:

- The possibility of rain water penetration into the siding, and into the space behind it, has to be eliminated. This can likely be accomplished by proper adherence to manufacturers' installation instructions.

- The build-up of high vapour pressure, in the cavity behind the siding, must be prevented.

Turning the siding into an open rain screen will accomplish both of the above. This means opening the spaces where siding elements are lapped, providing a cavity. Fastening the siding to furring strips such as plaster lathe or snow fencing boards will accomplish this.

It is suspected that the furring space between the siding and sheathing need not be more than 7-8 millimetres, provided that spaces between lapped joints can be maintained. This would not only make it possible to develop a low cost furring system, but it would also be possible to provide continuous support to otherwise flexible siding over the entire backing surface. Furring space should be kept to a minimum to reduce unnecessary loss of solar heat gain. A system is currently being developed at the University of Toronto. That notwithstanding, there is need for field evaluation of various systems under different climatic conditions.

7.5 Proposed Solutions for Existing Problem Siding

The removal and reinstallation of siding to correct siding problems must be viewed as an opportunity for increasing the thermal resistance and air tightness of the wall. Resistance to moisture related damage of the sheathing and within the wall system would be improved. It is the authors' opinion that insulating sheathing placed on top of the existing sheathing and the installation of an effective air barrier and siding with a furring space would solve the wall problems discussed in this report. The resulting energy savings will also contribute to the recovery of at least part of the investment.

7.6 Proposed Areas of Research

As detailed, there are a number of areas where further research is required to identify whether interior or exterior moisture is instrumental in causing the observed problems in siding. These are:

- Source of moisture - inside or outside. A carefully conducted laboratory study is necessary to determine the relative importance of inside and outside moisture sources to observed siding problems; the research should also establish the effectiveness of corrective measures.

- Development of fibre reinforced stucco system to be used with external insulation of walls. This would be a continuation of the HUDAC PHASE II basement insulation study. Of particular interest would be the control of cracking and the use of the stucco coating as an air barrier.

- Need for, and effects of, top venting of the furring space between the siding and sheathing.

8.0 BASEMENT MOISTURE PROBLEMS

8.1 General

Water leakage and dampness in basements have been, and still continue to be, common and costly problems. As a consequence, the quality of basement space is degraded, damage is caused to its components and a major source of indoor pollution and moisture is provided.

A better understanding of the interaction of moisture and heat flow through the basement materials system, combined with the development of new materials, now makes it possible to build basements which are virtually free from moisture problems.[20, 21]

8.2 Control of Basement Moisture

The basic concept used to control water and moisture damage recognizes that it is difficult to build barriers which will exclude water and moisture. A perfect barrier depends on flawless materials and workmanship, neither of which can be expected even under ideal construction conditions. Emphasis should, instead, be placed on managing water and moisture.

Examples where the management approach has succeeded are as follows:

- Moves towards the open rain screen wall which eliminates pressure difference and water transport across it by infiltrating air currents.

- The use of exterior insulation, to control moisture damage to basement wall materials by raising the wall temperature and, thereby, lowering the relative humidity in the wall materials.

- o The use of externally applied glass fibre basement wall insulation to lower the surrounding water table, thus eliminating the need to provide free draining backfill and crackfree walls.

Methods of controlling basement heat loss and moisture damage in existing housing[18] and in new housing[19, 20, 21] have been described in some detail elsewhere and will therefore not be repeated here.

There are five areas, however, that are of special interest to this investigation and warrant further discussion. They are:

1. Joist space condensation;
2. Soil drainage and radon gas;
3. Crawl spaces;
4. Slabs on grade;
5. Occupant generated moisture (clothes washing and drying, etc.).

8.2.1 - Joist Space Condensation

Band joist and sill plate condensation is frequently encountered where friction-fit batt insulation has been pushed into the joist spaces and a vapour barrier is lacking. Condensation in this location is primarily caused by vapour diffusion, as infiltration due to stack action dominates over leeward exfiltration due to wind. It is, therefore, not essential (but still desirable) to provide an air barrier to control condensation. Aluminum foil could, for example, be pushed over the insulation to act as a vapour (but not air) barrier without the need for making it airtight.

In mild but windy areas, where wind pressure dominates over stack action, exfiltration will occur and an air-barrier is essential. Carefully filled pieces of extruded polystyrene insulation, caulked with acoustic caulking, would be effective as a combination air/and vapour barrier and thermal insulation.

8.2.2 - Soil Drainage

The soil surrounding the basement walls and under the basement floor represents a major source of moisture. Measures taken to control the entry of moisture are also effective in controlling radon gas. There are two types of openings through which water vapour and other gases such as radon gas can enter the basement:

- Large openings through which gases are carried by air currents. These include cracks in the floors and drainage systems which lack effective vapour traps; and

- Small pores in the concrete, through which water vapour and radon gas penetrate by diffusion.

By keeping the number of drain pipes under the basement floor to a minimum, venting the sump to the outside, providing effective vapour traps on all drains and caulking the cracks in the basement floor, heat losses and moisture infiltration can be minimized.

To control entry of water vapour by diffusion, the walls and floors should be made as gas-tight as possible. Dampproofing of exterior wall surfaces, lower water/cement ratio concretes for walls and slabs and vapour barriers under floor slabs will accomplish this. For example, by placing a vapour barrier under a 70 m^2 basement floor slab of high water/cement ratio concrete, the rate of moisture evaporation through the floor slab could be reduced by as much as 3.0 kg/day. This reduction in the rate of moisture production would lead to a lowering of the indoor relative humidity by up to 10 percent, if the house is assumed to have a total floor area of 140 m^2 and experiences 0.3 ac/h. To reduce moisture infiltration into existing buildings, polyethylene sheets could be placed under carpets, or exposed concrete floors could be painted with vapour resistant paints.

8.2.3 - Crawl Spaces

Unheated crawl spaces present one of the most difficult problem areas to deal with. Conditions can become particularly severe during the summer, when the soil mass having been deprived of heat from the building above, is sufficiently cool to condense moisture from the exterior air. Swedish measurement show sustained relative humidities over 80 percent during the summer months, frequently exceeding 90 percent.[22*)]

This same Swedish report estimates that timber rotting during summer months can lead to a loss of mass of about one percent per year. It recommends that pressure treated wood be used in crawl space construction.

A necessary, but not sufficient, measure to control crawl space relative humidity is to reduce evaporation from the soil. Polyethylene sheet ground covers are generally disturbed, broken, or end up collecting water in low areas. A woven polyethylene sheet would be preferred because of its higher strength and the presence of small holes which would allow drainage of water trapped on tops of the sheet. This would still not guarantee, however, that the sheet will not be disturbed after it has been installed.

In view of the difficulties experienced, the use and value of unheated crawl spaces has to be seriously questioned.

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* This is an excellent paper containing a considerable amount of measured data of relevance to Canadian conditions. It should be translated and circulated.

8.2.4 - Slabs on Grade

One building examined in Thompson, Manitoba, had experienced serious condensation problems attributed, in part, to moisture gain from heating ducts embedded in the concrete floor slab on grade. Water was apparently leaking into the ducts and was then evaporated by the warm air of the forced air heating systems. In cases where the water table is close to the floor, casting of heating ducts into slabs on grade should only be considered if adequate thermal insulation is provided below the floor slab and if the water table can be kept below the bottom of the insulation.

8.2.5 - Occupant Generated Moisture

During this study it was found that some occupants of moisture troubled housing were storing large quantities of wet fire wood in the basements.* Regardless of how well the building is constructed, it will always be possible to exceed the limits the building can handle. It would seem unreasonable to set the standards for all buildings so high that the extreme occupant generated moisture loading can always be accommodated. Extreme cases should be recognized as such, and special measures should be taken to deal with them.

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* This is in addition to normal activities such as cooking, cleaning, clothes drying, etc.

9.0 OBSERVATIONS AND CONCLUSIONS

9.1 Observations

Notwithstanding the harsh climate, few nations enjoy housing of the quality found in Canada. Few nations are as wealthy as we are, and none use so much energy per capita.

Although there are some negative aspects to the Canadian housing industry, namely, the neglect in education, training, research and development and technology transfer, the positive aspects should be underlined:

- Problems pertaining to housing are often uniquely Canadian, and a considerable amount of experience is available in this country. The danger of imports replacing our own products is far smaller than, say, in the automobile industry. Indeed, the reverse could be true. We are in a position to export technology, as well as manufactured goods, to other cold region nations.

- For a relatively small amount of expenditure per kilowatt hour saved, our space heating consumption can be reduced substantially. For example, it has been shown that basement heat losses can be reduced by 50 to 80 percent, through thermal retrofitting, with a payback period ranging from two to five years.

- Retrofitting of existing and construction of new housing is highly labour intensive. At the same time, little capital for new machinery is required. It is a market with a large potential for creating jobs at relatively low costs.

- The impact of thermal retrofitting of housing to reduce energy consumption will have a large impact on employment and the building product manufacturing industry. Again, taking residential basements as an example, it has been estimated that 14 million megawatt hours per annum, worth over one half billion dollars per annum*, would be saved if all the pre-1975 residential basements in Ontario were to be insulated to an R(SI) level of 1.6 m^2C/W. The estimated materials and labour cost would be about four billion dollars. (This figure also includes repairs not associated with energy conservation and are therefore not included in the energy savings cost payback calculations.)[18)]

9.2 Conclusions

The housing industry should be viewed as an industry which can provide quality housing, a reduction in energy consumption and, if desired, a reduction of unemployment and an increase in the demand for products from the manufacturing industry. It is not a neglected industry, but an industry where total system redesign including attention to moisture problems, energy requirements, venting for health and other reasons, with full co-ordination of all participants, including building products manufacturers, has not taken place.

To realize its full potential, the organization of the industry and the support and services provided to it must be examined. A unique organization with broad-ranging powers and the ability to engage building systems research would have the necessary access to the information needed to establish the status of the industry and recommend changes.

The following are suggestions which will need to be carefully researched and considered in the overall context. They represent impressions arising from the present investigation, as well as observations over the years in Canada and abroad. The suggestions and opinions are those of the author:

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* Assuming oil heating with a seasonal furnace efficiency of 0.6.

o Information Transfer and the Creation of New Knowledge

There is a very large gap between what knowledge exists about various aspects of housing and what is put into practice. A substantial amount of Canadian building science research has been carried out and reported. In spite of the efforts made to transfer this knowledge to engineers, architects, manufacturers, builders and the trades, the results have been largely ineffective. With relevance to the present investigation, the causes for moisture damage and ways of avoiding it have been well documented and circulated in publications such as the Canadian Building Digest. Suggestions in the Digest are, however, not always transferred to the field. Clearly, there is much need for improvement in this area.

A second gap exists between the knowledge which exists and the new knowledge that needs to be created to maintain, and even increase the Canadian lead in this area. This is particularly important when one considers the impact of Government rehabilitration programs.

o Government Policy

Lack of communication and the possibility for duplication appears to exist, not only between the various levels of government, but also within the same levels. For example, in an attempt to conserve energy, the Federal Department of Energy, Mines and Resources has been given the responsibility of managing the CHIP program. To manage this program properly requires an understanding of the mechanical aspects of thermal retrofitting and the effects of these changes on the behaviour of the building envelope and the building program itself. In these areas we find expertise in DBR/NRC and CMHC. The consequences of wrong decisions, or policies which do not consider all aspects of the problem, can limit future opportunities for additional energy conservation and, in extreme

cases, lead to damage of the building. For example, if the attic is insulated first, it may not be practical to seal off air leakage into the attic at a later stage. This means that an important energy conservation opportunity is lost due to improper sequencing. But the more serious consequences of this could be moisture damage to the attic.

Governments play an important role in the building process. To be more effective, efforts at various government levels and departments could be better coordinated. Also, industry is not always aware of the services and information available from various government agencies.

o Codes and Standards

New standards emphasizing energy conservation have indirectly contributed to moisture damage. If airtightness, in terms of ac/h under known conditions, is legislated, details for building components which are known to lead to successful airtightness solutions and which are proven to avoid moisture damage, could also be legislated.

Denmark, for example, has forbidden the use of flat roofs. One item which should be considered in light of the proposed National Building Code minimum thermal resistance values, is the installation of insulating sheathing rather than in a thicker stud cavity. The improvement in the total system efficiency of the wall with insulated sheathing over the wall with thicker studs, is just as important and predictable with respect to energy conservation as the increase in the overall R-value. But more significantly, exterior insulating sheathing makes it possible to install an effective air-barrier over joist spaces. This, in turn, will reduce air leakage and interior wall surface condensation and reduce the growth of mould and mildew.

One possible approach here could be that used in the Swedish National Building Code (SBN), where the mandatory parts specify performance, and proven methods which meet the performance criteria are provided in the body of the code, as well as in separately issued commentaries. This approach has the added benefit of making it possible to respond quickly when problems are recognized, without having to wait for the issue of the next code.

Also, the National Building Code of Canada could pay more attention to regional problems. While this would lead to a bulkier and more complex code, it should make it possible for provincial adoption of the National Building Code with fewer changes. The climatic regions, which are shown in this study to be very important, do not follow provincial boundaries and the special needs, peculiar to climatic aspects, are more rationally handled in the national code.

o Building Officials

The quality and extent of building inspection needs to be upgraded. In most instances, the building inspector is the best qualified expert available to the builder. Methods should be derived whereby the inspector can also provide advice to the builder, without at the same time having to assume responsibility for problems arising from the advice provided. "Fact sheets" could be generated, which deal with the majority of recognized problem areas. Such "fact sheets" could be considered as an extension of the Building Code Commentary. The Basement Installation Manual and the Manual on External Insulation of Basements fall into this category. These documents were prepared by the Foundations and Drainage Subcommittee of HUDAC in close cooperation with CMHC, DBR/NRC, the major insulation manufacturers and Building Science researchers from universities. CMHC has played a significant role in this work, both by providing technical input as well as financial support.

What is particularly attractive in such an approach is the assurance that all parties concerned have played an active role in the development of the techniques, providing broader acceptance by all concerned.

o Education and Training

Traditionally, education in Building Science in Canadian universities has been inadequate, if not altogether nonexistent. The main reason for this has probably been the division of responsibility between architects and engineers in the Provincial Acts. While in the late sixties and early seventies, there was active encouragement from DBR/NRC to establish centres of excellence in building science research and training, these centres did not always receive the required encouragement and support from universities. Under the present strained fiscal conditions, it is very difficult to find funding within existing university budgets to support the creation of new building science courses, laboratories, and the acquisition of qualified staff. Even if funding were available, it would be difficult to obtain qualified staff since the demand for experts by industry is high.

One way of quickly establishing building science programs in Canadian Civil Engineering departments would be through the creation of endowed chairs of building science. This would place the money specifically where it was needed. The terms of reference should restrict the use of money for teaching and research in building science. While every university does not necessarily need a comprehensive building science program, a minimum goal would be the offering of one undergraduate core course in building science. (The undergraduate Civil Engineering students at the Royal Technical Institute in Stockholm have access to three building science courses and additional courses dealing with acoustics and mechanical systems.)

Support for postgraduate research has improved significantly with National Science and Engineering Research Council (NSERC) operating, strategic and equipment grants. Similarly NRC and CMHC scholarships are making it easier for students to continue postgraduate studies. Provincial grants are also starting to become available. The level of support should, however, be increased.

More direct industry involvement in university research would be of benefit to all concerned. This is particularly the case with the building industry, which is fragmented and lacks a tradition of carrying out research. Joint projects between the Building Science Group at the University of Toronto and CMHC, HUDAC and the major thermal insulation manufacturers have been successful in providing support to the industry and meaningful training for postgraduate students. Much more could be accomplished if more academic and technical support staff at universities were available.

An important aspect of university education is the provision of continuing education courses to update practicing engineers and architects. Lack of funding for qualified staff is curtailing the development of such training courses. Special summer courses should be offered, on a wide geographical basis, to staff at technical schools and community colleges. Universities with established building science programs and laboratories would be in an excellent position to offer such continuing education.

o Research and Development

A substantial amount of information has been generated by building research establishments, industry and universities. This information needs to be coordinated, since the cost impact of minor improvements to existing methods and materials can be very substantial.

In addition to more funding and incentives for building research, in order to avoid unnecessary duplication, the research effort needs to be better coordinated internationally. Costly duplication of effort and, above all, repeating mistakes made by others, which in the building industry can be very costly (ureaformaldehyde insulation, radon gas) to rectify, can be minimized.

In Canada, attempts should be made to develop an information system to co-ordinate research, planned or in progress. This would avoid unnecessary duplication, as well as provide co-operation between those working in the same area.

o Technology Transfer

The existing methods used to transfer technology have not proved successful. Architects and engineers have not kept up with modern developments, a situation even more prevalent with the various trades. New methods and media for transferring knowledge must be developed.

Information and an awareness of the implications of changes must reach the trades, it may be necessary to legislate attendance at centrally offered practical demonstrations in order to maintain trade registration. The licencing of trades involved with the installation of insulation and the air and vapour retarders has to be seriously considered.

o The Occupant

Although the occupant has certain rights where social housing, assistance in retrofitting, or warranty programs are involved, these should not be without responsibilities. This current investigation identified numerous cases where the lifestyle of the occupant reached extremes of moisture production for which housing can not be economically protected. Yet, the builder or

manufacturer is accused of having caused the failures and, jointly with warranty programs, bears the cost of rectifying "problems".

It is recommended that each home be provided with a set of "operating instructions" regarding various components which will establish the limits of abuse. Such instructions should be written in simple language and be permanently displayed in a convenient location. Moisture gauges could be distributed, which by colour or other means, indicate that sustained high relative humidities have allowed moisture accumulation which could lead to damage unless extra ventilation is provided.

The foregoing are a number of suggestions and recommendations that relate directly to this particular research program. It should be recognized that a number of important forces are currently at play and that the drive towards energy convervation will lead to the utilization of new materials and construction practices.

It is, therefore, imperative that a system approach to building design be taken so that the total effect of change to current practices can be properly evaluated before new materials, practices or conventions are introduced.

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Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

MOISTURE INDUCED PROBLEMS IN NHA HOUSING

PART 3 OF A 3 PART SERIES

APPLICABLE MOISTURE REDUCTION TECHNIQUES FOR NEWFOUNDLAND

Prepared For:
The Research Division
Policy Development and Research Sector
of
Canada Mortgage and Housing Corporation
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Caution

The analyses, interpretations and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation, which assisted in the study and its publications. The results of the study are published for information purposes and the reader is cautioned that the statistical and scientific data generated herein are derived from a study of a select few Canadian moisture-troubled homes.

Extrapolation of this data to most houses in Canada and to houses in other countries and climates may be feasible, provided that the vagaries of climates and the behaviour of housing systems and building materials in those areas are understood.

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EXECUTIVE SUMMARY

1.0 Background

This report, on possible moisture reduction techniques for Newfoundland NHA housing (primarily a passive venting stack) forms part 3 of a larger 3 part study, which specifically investigates moisture related problems in NHA housing across Canada.

Because of the large reported incidence of moisture related problems in Newfoundland housing, one component of the overall study was to investigate, on a priority basis, the possibility of utilizing vent stacks as a practical solution for moisture reduction in Newfoundland houses.

Other methods of moisture reduction were also investigated.

Components of this study include:

- Sources of moisture and moisture loading

- Methods of moisture removal by:

    - o passive ventilation
    - o mechanical ventilation
    - o refrigeration systems

- Capital and Operating costs associated with each system

Other work is continuing on this subject by manufacturers, educational institutions and various government agencies. In any case, the subject of moisture removal is inevitably linked

with energy considerations. There is a complex relationship between the energy load and moisture generation. Cost of additional energy will probably be one of the most significant factors in selecting a suitable method for reducing interior moisture levels and preventing moisture related damage in housing.

2.0 Discussions

This report deals only with NHA Housing units in Newfoundland, which according to survey information, were all electrically heated.

Although the effect of pressure changes on housing with chimneys for fireplaces or fossil fuel systems was not overlooked, the recommendations and conclusions made in this report are restricted to homes with flueless heating.

Since suitable residential air quality standards for housing were not found, the consultant did not make specific recommendations on fresh air requirements. It is assumed that ventilation provided to reduce humidity to acceptable levels will ensure proper air quality. Further research in this area is necessary, as an unacceptable level of uncertainty exists regarding the health aspects of high humidity levels and mould growth.

Airtightness tests were not carried out and air infiltration was calculated and assessed based on survey information data. Any future test program must, therefore, include an airtightness test to ensure proper evaluation of the results.

The use of dehumidifiers (refrigeration systems) to reduce moisture content does not address air quality in the house.

Improved future refrigeration equipment performance, as a means of reducing high moisture levels, should not be considered as the simple solution since fresh air needs must also be addressed.

Moisture problems in housing are, to a degree, occupant dependent. Life-style, family size, furnishings, furniture location, and air circulation, all contribute to the degree of the problem. The ultimate solution must be flexible enough to accommodate the normal variations in these factors. Occupant generated moisture can lead to high internal RH levels which, in turn, can result in condensation on the wall or interstitially, causing mold and mildew or, in extreme cases, rot of structural members.

The high wind conditions in Newfoundland create pressure conditions around the house structure, which can not be accurately determined without detailed field investigations. Field test work, rather than laboratory tests, are also required to evaluate the effect of wind on various building systems.

The location of a passive vent stack and its performance under various wind spreads (ranges in speed and direction) can, currently, only be forecasted based on previous published empirically established recommendations for chimneys. It is recommended that tests be carried out to establish, accurately, the performance of a stack under varying internal and external conditions. (Relative humidity, wind velocity and direction, etc.).

This component of the study concluded, on a theoretical approach basis, that because of the high moisture content of the ambient outside air in Newfoundland, and the relatively warm winter temperatures, passive ventilation alone (vent stacks) may not be a practical solution.

Recommendations for a test program to arrive at an optimum system of removing excess moisture in a house are included in this report.

3.0 Sources of Moisture and Moisture Loading

Moisture in housing is generated from three basic sources:

- moisture contained in the ambient outside air,
- moisture created by the house occupant through normal every day activities such as cooking, washing, and other housework,
- moisture supplied by the soil, through basement walls and floors.

In most parts of the country, during the heating season the ambient outside air is fairly dry and, natural ventilation (normal infiltration/exfiltration through the building envelope) will adjust internal relative humidity to acceptable levels. In Newfoundland however, high outside vapour pressures (above 80% relative humidity at 0°C; representing 0.003 kg of moisture content per kg of air), are maintained during a major portion of the winter season. In addition to this base level, which represents a Relative Humidity of about 20% at 22°C (71.6°F), everyday activities can easily add an additional daily moisture loading from 10 to 18 kg of moisture, depending on family size and time spent in the house.

As a result of these factors, inside Relative Humidity readings for Newfoundland houses of 50-70% are common.

4.0 Methods of Moisture Removal and their Cost

Because traditional methods of venting have largely disappeared in newer, air tight flueless housing, internally generated moisture can only be practically removed by one or a combination of the following:

- o Ventilation
- o Mechanical Dehumidification

Each of the above methods, and their practical use in Newfoundland, is discussed in this report.

It is concluded from the calculations in this report that, with a passive stack ventilation alone, it is difficult to remove enough moisture from the house to lower inside Relative Humidity to an acceptable level. Operating costs associated with passive stack ventilation are also high. An estimated additional monthly heating cost of up to $20 is forecast ($160 per year 1982 costs)[1]. Over a 15 year lifecycle, this represents a total discounted cost of $2 760 (15% discount rate).

Mechanical ventilation, by means of a central ventilation system, is a better solution (ventilation rates can be reasonably adjusted and controlled as required for inside moisture levels). However, this method does not present a realistic solution for retrofit[2] and, used as a new installation, capital costs are also high and are estimated at $1 900-2 500.

---

1) 8 month heating season only.
2) Simple payback is estimated in excess of 30 years.

Mechanical ventilation is, however, attractive as it permits the inclusion of heat recovery systems. Net heat losses with heat recovery are expected to be small and it is estimated that the total additional energy cost of ventilation for moisture removal will be $10 per average winter month or less if heat recovery devices are installed.[1] See Figures 3.8 and 3.9 in the main body of the report.

Small portable dehumidifiers are currently available. However, these are designed for basement dehumidification during the summer months and are not capable of lowering room temperature Relative Humidity levels below 50%.

It is expected that more efficient units could be produced, or industrial/commercial types modified and adapted for residential use. Future capital costs are, therefore, a function of expected production volume forecasts.

Before a particular solution is applied to a large number of houses, it is essential that all the proposed methods be field tested in Newfoundland for effectiveness, and note any unpredictable complications that may arise during their use.

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1) As a new installation, simple payback is estimated at 14 to 15 years over natural ventilation.

1.0 INTRODUCTION

The purpose of this report is to detail the Consultant's findings on the theoretical aspects of designing a passive venting system to reduce inside humidity and minimize moisture induced damages to NHA housing in Newfoundland. These theoretical results have been correlated with empirical results from the "Ottawa Test House"[1)] and the results of a field survey of NHA Housing in Newfoundland.

This report forms part of a larger contract with CMHC to evaluate Moisture Induced Problems in NHA Housing.[2)] Although, the terms of reference for the project specifically requested a vent stack solution for Newfoundland, it was clear early in the work, that other methods of reducing moisture content in housing should also be explored. The work statement was, therefore, expanded to include other possible methods of dehumidification.

Other methods of moisture removal and practical use of various other systems have been reviewed. Capital and operating costs have been calculated for alternate systems.

This report contains some definite conclusions regarding the possible means of removing moisture from housing units in Newfoundland. Conclusions and recommendations for further specific research are contained in the final chapter.

---

1) Contract between T.E.S. Ltd., Ottawa and Canada Mortgage and Housing Corporation, Project Implementation Division.

2) Contract 176-4-25 between CMHC and Marshall Macklin Monaghan Limited

Although this report contains certain approximations and assumptions, it should be recognized that actual field conditions are difficult to predict. As an example, a poorly fitted window or even a tree located close to a house, could significantly affect ventilation rates derived from theory.

The minimal energy consumed by the fractional horsepower motors used to drive the various pumps and fans discussed in this report have also been ignored.

The conclusions, contained in this report are, therefore, based on calculations judged to be sufficiently accurate, given the wide range of actual field conditions known to exist in Newfoundland.

2.0 SOURCES OF MOISTURE

2.1 General

Moisture within a building is generated by normal, everyday activities and also by infiltration of moisture laden air through exterior walls, floors and ceilings.

In winter, the outside vapour pressure is generally lower than the inside vapour pressure. Consequently, moisture flows from the inside to outside of the building . In addition, basement walls and floors, if not properly treated, may permit ground water to pass through the structure, either through leaks or as diffused vapour. This moisture source can contribute considerably to the inside humidity levels.

In most situations, however, the major portion of moisture present within the building enclosure is that generated by the house occupants.

2.2 Moisture Generation Within a House

Daily activities, such as washing, cooking, and clothes drying, all add to the amount of moisture in the air. Therefore, the amount of moisture generated depends largely on the number of occupants, their living habits and the amount of time they spend at home.

Although it is difficult to assess the amount of moisture created by various activities (because available data is not consistent), Table 2.1 lists approximate amounts of moisture produced for different activities by a family of four. These values have been established by National Research Council of Canada (NRC), are currently in general use, and have been used in subsequent calculations in this report.

TABLE 2.1

AVERAGE MOISTURE PRODUCTION[1)]

Activity	Moisture Produced (kg/day)
Cooking (3 meals per day)	0.90
Dishwashing (3 meals per day)	0.50
Bathing - Shower	0.23
- Tub	0.05
Clothes drying indoors or with unvented dryer (per wash day)	11.70
Floor mopping (per 10 m^2)	1.40
Occupants (family of four per day)	5.40
Basement contribution	(not known)[2]

2.3 Occupant Created Moisture Loading

Occupant contribution to moisture, over a 24 hour cycle, is assumed to be the most significant factor (confirmed by field test data collected during this project)[3)]. A more detailed calculation is, therefore, carried out below.

As set out in the ASHRAE Guide, ("Fundamentals' Latent heat gain from occupants"), the heat gain per person, adjusted for a normal percentage of men, women and children is as follows:

Seated, light work	75 watts (255 BTU/h)
Seated, at rest	40 watts (137 BTU/h)
Sleeping (70% of metabolic rate of seated, at rest)	0.7 x 40 = 28 watts (96 BTU/h)

---

1) National Research Council, "NRC 13487, Walls, Windows and Roofs for the Canadian Climate, J.K. Latta, 1973.

2) The contribution from the basement is unknown but thought to be significant in some instances. Research in this area is currently underway.

3) Field survey of 201 housing units and occupant interviews conducted across Canada.

To estimate the moisture produced by the house occupants' metabolic rate, two variables should be considered; the number of occupants and the percentage of time the house is actually occupied. A third variable, degree of activity (i.e. light work, at rest or sleeping), varies from one household to another, but the effect on moisture production is not as significant as the first two. Therefore, 8 hours of sleep and seated light work for the remainder of the day will give a realistic representation of daily moisture generation by the house occupants.

TABLE 2.2

TYPICAL MOISTURE PRODUCTION

No. of Occupants	Day Hours Spent Outside	Latent Heat (watt-hrs)	Corr. Factor [1]	Daily Moisture Production (kg/day) [2]
4	0	(75x16+28x8)x4	x 0.75	6.14
4	4	(75x12+28x8)x4	x 0.75	4.85
4	6	(75x10+28x8)x4	x 0.75	4.20
4	10	(75x6+28x8) x4	x 0.75	2.90
6	0	(75x16+28x8)x4	x 0.75	9.20
6	4	(75x12+28x8)x4	x 0.75	7.27
6	6	(75x10+28x8)x4	x 0.75	6.30

1) Since base data is for 78°F (25.6°C), a corrective factor of 0.75 was applied to reflect a more normal condition of 72°F (22°C) - Carrier System Design Manual, Part I.

2) Calculated at standard conditions, i.e. 1 lbs. of moisture is 1 076 BTU latent heat.

For a family of four, at home for an average of 20 hours, daily moisture generation is as follows:

TABLE 2.3
SOURCES OF MOISTURE

Source	Daily Moisture Producion (kg)
Occupants	4.85
Plants, pot size 8", watering once a week 3 litres/pot x 3/7 (three pots)	1.29
Cooking	0.90
Dishwashing	0.50
Bathing (Shower)	0.23
Clothes washing	1.80
Clothes drying; neglected, as this should be done outside or dryer should be vented outside (1)	
Floor mopping: (15 m^2, twice a week) 15/10 x 1.4 x 2/7	= 0.60
Total/day	10.17

The moisture generated by clothes washing is not averaged over the week, i.e. a clothes washing day is selected as a typical day. Moisture loading due to clothes washing occurs during half a day or less. If not removed by a ventilation system or by other proposed systems, this moisture will dissipate through undesirable mechanisms, such as condensing on cold surfaces or interstitially if it can escape through openings in the vapour barrier. More washing days occur in families with several children.

1) If clothes are dried inside the housing, this will add 6/4 x 11.7 ≅ 17.6 kg of water

A similar calculation for a family of six, at home an average of 20 hours, results in an average moisture generation of 15 kg/day and a possible peak load during washday of up to 33 kg/day.[1)] For a family of six, at home all day, moisture loading could increase to 17 kg/day and 35 kg/day[1)] respectively.

Both the size of family and the amount of time they are at home are, therefore, critical in determining the amount of moisture generated within the home.

1) If clothes are dried inside the housing, this will add 6/4 x 11.7 ≅ 17.6 kg of water.

3.0 MOISTURE REMOVAL

3.1 General

Water vapour in the air will first condense on cool surfaces of exterior walls and windows. To minimize conditions which can potentially result in structural damage or unsightly and unhygienic mould growth, excess moisture build-up in a house must, therefore, be prevented. Also, if relatively higher inside vapour pressures exist, inside air can move through the defects in the air vapour barrier and carry a considerable amount of water. If the dew point occurs within the insulation or other parts of the structure, water will form and could accumulate interstitially, causing loss of thermal resistance of the wall or perhaps structural damage.

Moisture diffusing through the basement walls and floor can be minimized by better construction techniques and insulation methods. In existing houses, moisture diffusion into the basement can be reduced by sealing basement floors and walls.

Because traditional methods of venting have largely disappeared, internally generated moisture must be removed from newer, air tight, flueless housing by other means such as one or a combination of the following:

- Ventilation
- Mechanical Dehumidification
- Chemical Dehumidification[1)]

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1) Chemical dehumidification is possible and, in fact, is commonly used in industrial applications where low air moisture contents are required. However, because of the complexities of this type of system, these techniques are not judged to be appropriate for a residential application and have not been discussed in this report.

Ventilation and mechanical dehumidification and their practical use in Newfoundland are discussed in the following sections.

3.2 Ventilation

Ventilation methods, discussed here, are for the purposes of removing the moisture from inside the house (internal ventilation). The methods discussed should not be confused with structural ventilation, whose purpose is to prevent moisture accumulation in building members, which can include drying crawl spaces, attics, or any enclosed area outside the volume normally enclosed by the vapour barrier of the house.

In addition to moisture removal, ventilation provides fresh air for comfort and health. This factor is especially important in the case of tightly constructed electrically heated houses, where normal air changes can be expected to be only one in every two hours (½ air change/hour) or less.[1)]

Ventilation is only effective in moisture removal when the moisture content (or vapour pressure)[2)] of the outside air is lower than the vapour pressure of the air inside the house. In this instance, each m^3 of inside air exhausted will remove an amount of water equivalent to the difference in moisture content between the inside and the outside air.

The amount of outside air required to reduce inside relative humidity levels depends, therefore, on many factors including the following:

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1) Although this is a generally accepted value, a review of literature suggests significantly lower values of 0.3 air changes/hour or less. For a further discussion on air tightness, see part 2 of this research project.

2) In this instance, the relevant measure would be kg of moisture per kg of dry air.

- Moisture produced within the house
- Relative humidity to be maintained inside the house
- Inside dry bulb temperature
- Outside dry bulb temperature and relative humidity

The level of the moisture content to be maintained inside the house affects the ventilation requirements significantly. Ventilation also becomes less effective in removing moisture as the outside temperature and relative humidity increase (increasing vapour pressure). As the humidity of the inside air is lowered, there will be less vapour pressure difference between inside and out, reducing moisture transmission due to differential vapour pressures. Also, with high internal moisture generation, a larger volume of outdoor air is required to replace inside air in order to maintain low inside relative humidity levels. (Figure 3.1)

Although a "safe" level of inside vapour pressure cannot be determined[1], an inside relative humidity of 27% at 22°C (71.6°F) will decrease moisture transmission to generally acceptable levels.

3.3 House Ventilation Requirements

Ventilation requirements (for a house with four occupants) have been calculated for typical Newfoundland conditions with outside winter and spring temperatures varying from -15°C to 0°C at 80% Relative Humidity. It is assumed that occupants will be at home 20 hours per day. For a representative calculation, inside conditions are selected as 27% RH and 22°C (71.6°F) temperature. If clothes are dried inside the house, significantly higher levels of ventilation will be required. (These levels have not been calculated.)

---

1) The "safe" level will require further field investigations. Inside and outside vapour pressures and wall conditions will need to be monitored on a continual basis for some considerable length of time.

For comparison purposes, all calculations are repeated for a family of six.

As Table 3.1 indicates, ventilation requirements vary significantly with the changing moisture content of outside air. As the outside air temperature and humidity increase to the levels generally experienced in Newfoundland, very high ventilation rates are required in order to maintain low moisture content levels inside the structure.

3.4 Ventilation Systems Available

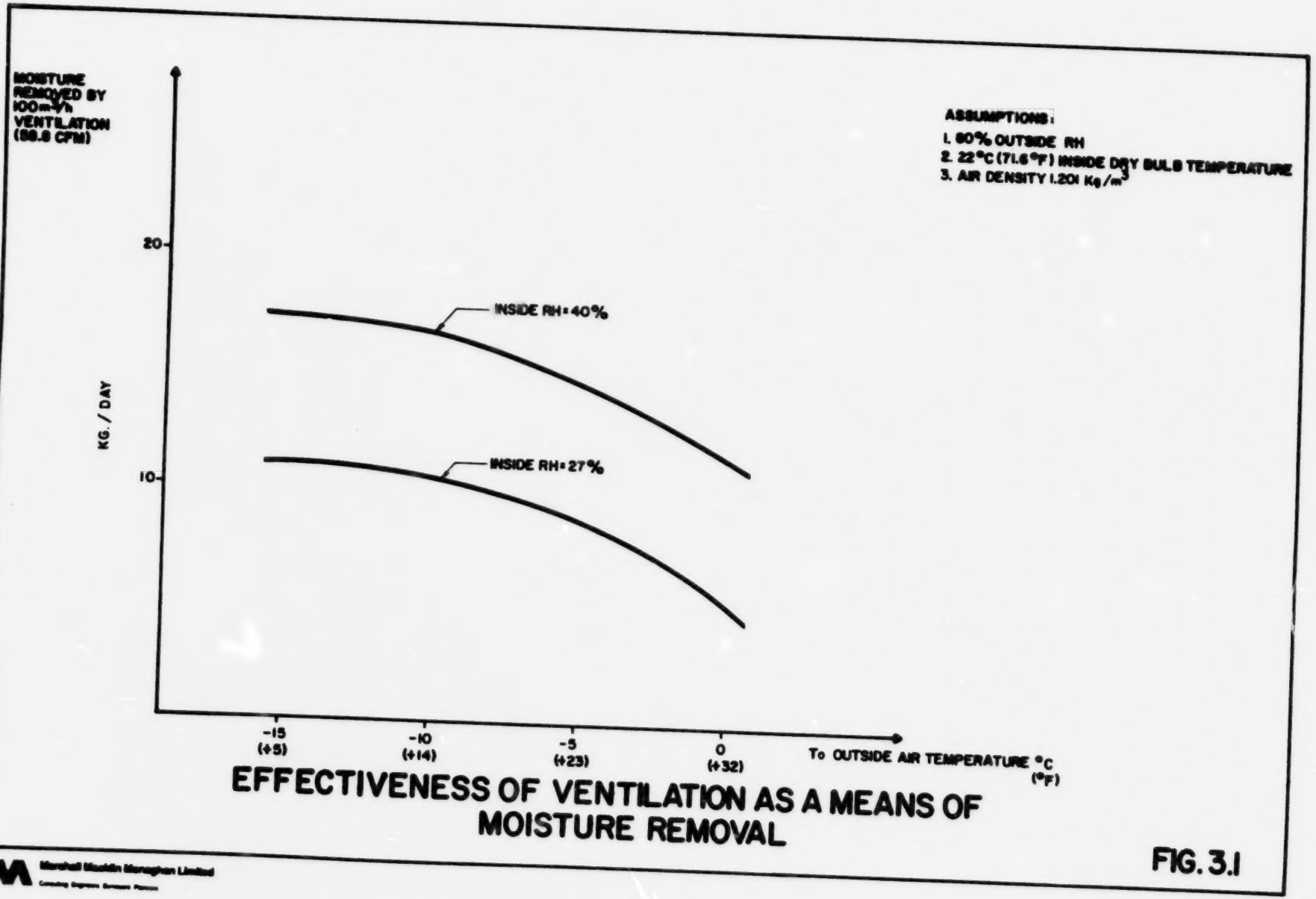
Ventilation can be provided either by a passive system (a vent stack) or a mechanical ventilation system. For purposes of this project, CMHC directed the consultant to investigate the reduction of internal Relative Humidity levels by means of stack ventilation. It is the opinion of the consultant that this method is limited in its application to moisture reduction, in spite of its capabilities to provide a fail-safe mechanism for dangerous pollutant reduction. Accordingly, other methods of air moisture content reduction have also been investigated and are discussed later in this report.

3.4.1 Ventilation by Means of a Stack - General

For purposes of discussion (and description) a vent stack is defined as a circular pipe of metal or plastic extending from the lower side of the ceiling in the highest (uppermost) habitable area and extending through the attic space to an exit point above the roof membrane.

This stack serves two purposes:

- it provides ventilation by exhausting warm and humid air from the inside;
- it increases the height of the neutral pressure plane.



EFFECTIVENESS OF VENTILATION AS A MEANS OF MOISTURE REMOVAL

FIG. 3.1

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TABLE 3.1

TYPICAL VENTILATION REQUIREMENTS

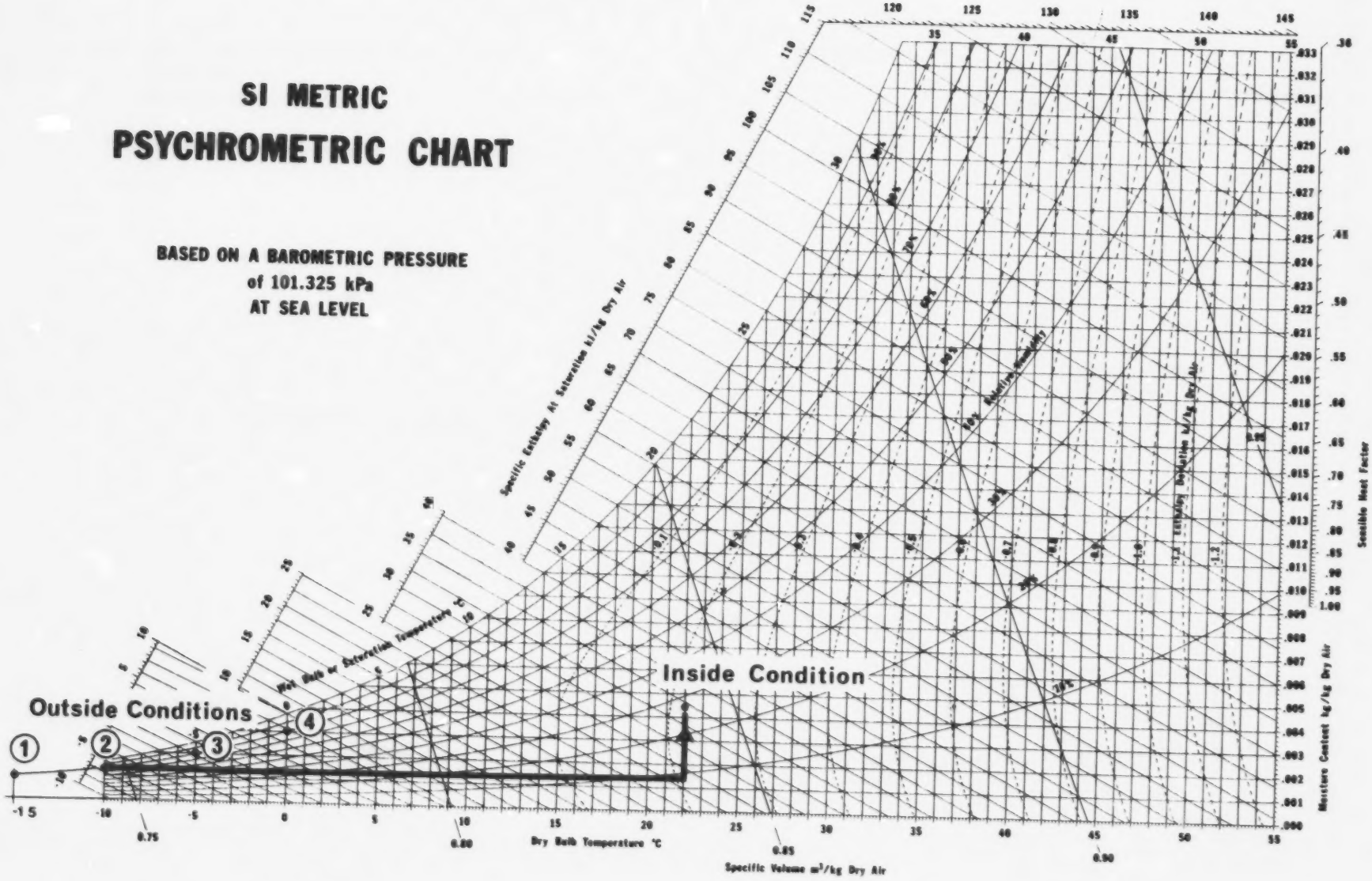
Outside Air (db) Temperature, (RH = 80%)	Moisture Content Difference kg/kg	Ventilation Requirements m^3/h (l/s)					
		Family of Four[1] 10.17 kg Moisture[3]		Family of Six[1] 15.26 kg Moisture[3]		Family of Six[2] 17.19 kg Moisture[3]	
-15°C	0.0038	95	(26)	142	(39)	161	(45)
-10°C	0.0036	100	(28)	150	(42)	170	(47)
- 5°C	0.0028	129	(36)	193	(54)	219	(61)
0°C	0.0018	200	(56)	300	(83)	338	(94)

See the psychrometric chart (next page) for moisture content values.

1) away 4 hours per day
2) home all day
3) daily moisture production

SI METRIC
PSYCHROMETRIC CHART

BASED ON A BAROMETRIC PRESSURE
of 101.325 kPa
AT SEA LEVEL



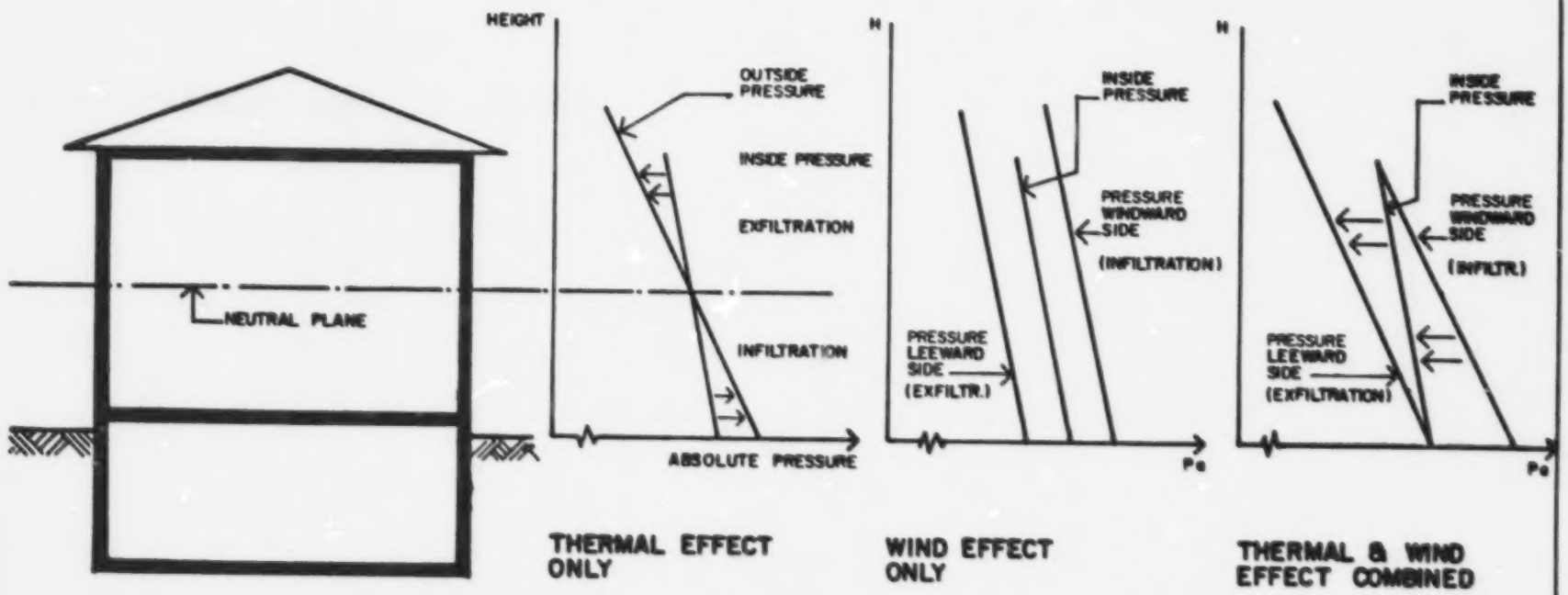
Increasing the height of the neutral pressure plane thereby reduces exfiltration through the higher parts of the exterior walls.

Wind forces affect the location and slope of the neutral pressure plane. It may, therefore, not be possible to totally eliminate exfiltration utilizing only a passive stack (of reasonable height).

Figures 3.2 and 3.3 describe typical pressure profiles under different conditions. The figures illustrate that any appreciable wind velocity will create negative pressures on the leeward side, overriding the negative pressure inside the house caused by a stack. This phenomenon makes precise calculations regarding the effectiveness of moisture reduction by means of passive ventilation very difficult.

In summary, the following are the parameters that must be taken into account when designing a non-mechanized (passive) ventilating stack.

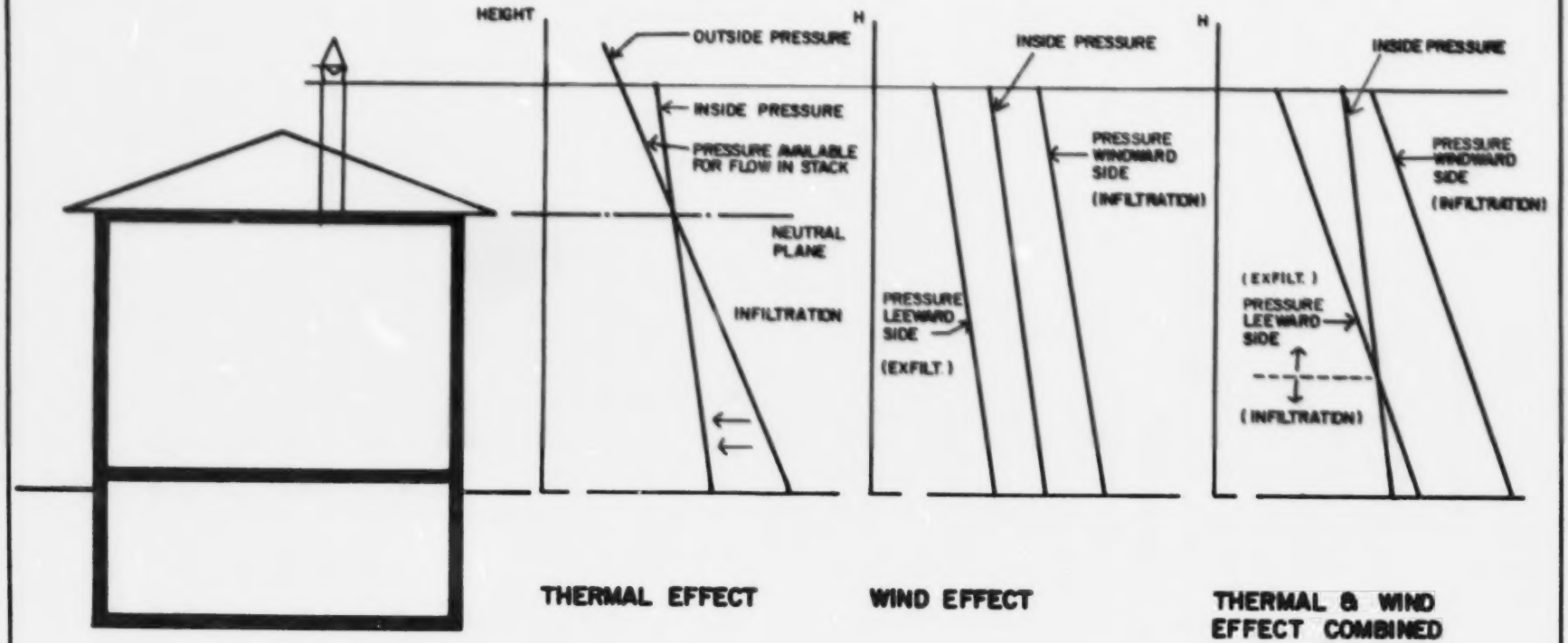
- ventilation requirements (moisture load to be removed)
- total effective area of cracks and openings on exterior walls, around windows, etc.; (pressure tests are required to determine this)
- normal inside/outside temperature differential;
- allowable height of the stack (practical and code restrictions);
- prevailing wind velocities and their effect on stack efficiencies. It should be noted that stack caps and micro-conditions caused by roof designs will also affect stack performance.



HOUSE WITHOUT STACK, PRESSURE PROFILES

Note : Equal Distribution Openings, Cracks along Height Assumed.

FIG. 3.2



HOUSE WITH STACK
PRESSURE PROFILES (TYPICAL)

Note : Equal Distribution Openings, Cracks along Height Assumed.

FIG. 3.3

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3.4.2 Practical Stack Design for Newfoundland

It is possible and desirable to raise the neutral pressure plane close to or into the attic space; however, its ultimate location will depend on the distribution and resistance to air flow of openings in the building envelope.

With respect to the theoretical performance of the stack, the lower opening is the effective crack area in the building envelope, while the upper opening is the actual stack and the effective crack area above the neutral pressure plane. Increasing the stack diameter will, therefore, increase the height of the neutral plane only if the effective crack area is sufficiently large. Other important design factors include the pressure loss through the air entrance at the bottom of the stack and the discharge loss at the rain cap. Additional resistance, which will result in a lowering of the neutral pressure plane is introduced by a volume control damper or a bird screen.

When the top of the stack is 1.25 metres or more above the neutral pressure plane, the positive pressure difference developed above the neutral plane is adequate to permit the use of reasonably sized stacks (up to 250 mm).

The effectiveness of a passive stack, as a means of non-mechanical ventilation, depends on the stack height. At zero wind speed, stack effectiveness is linearly proportional to the stack height. Stack effect (pressure difference between the inside and the outside) can, therefore, be expressed by the following formula: (Wind effects omitted)

$$Pc = 0.0342\ P.h.\ \left(\frac{1}{T_o} - \frac{1}{T_1}\right) \cong 3\ 465\ h\ \left(\frac{1}{T_o} - \frac{1}{T_1}\right)$$

Pc: Stack effect at height h, (Pascals)

P: Atmospheric pressure = 101 325 Pascals

h: Height above or below the neutral pressure plane, (m)

T_o: Outside temperature, °K

T_1: Inside temperature, °K

Figure 3.4 provides the results of calculations for a range of inside-outside pressure differences (P_c - theoretical draft) for different values of h (height below or above the neutral pressure plane) and the range of outside temperatures expected in Newfoundland (T_o - outside temperature).

Figure 3.5 shows the ventilation rate expected for different stack heights, outside temperatures and stack diameter.[1)]

Figure 3.6 shows the calculated values of moisture removed (kg/day), expressed as a function of outside temperatures and stack heights. A typical Newfoundland air tight "troubled" house and typical Newfoundland outside relative humidities of 80% have again been assumed. On this graph, the two broken lines indicate the moisture generated by the different families. Family "A" designates a family of four who are at home an average of 20 hours a day, while family "C" designates a family of six who are home all day.

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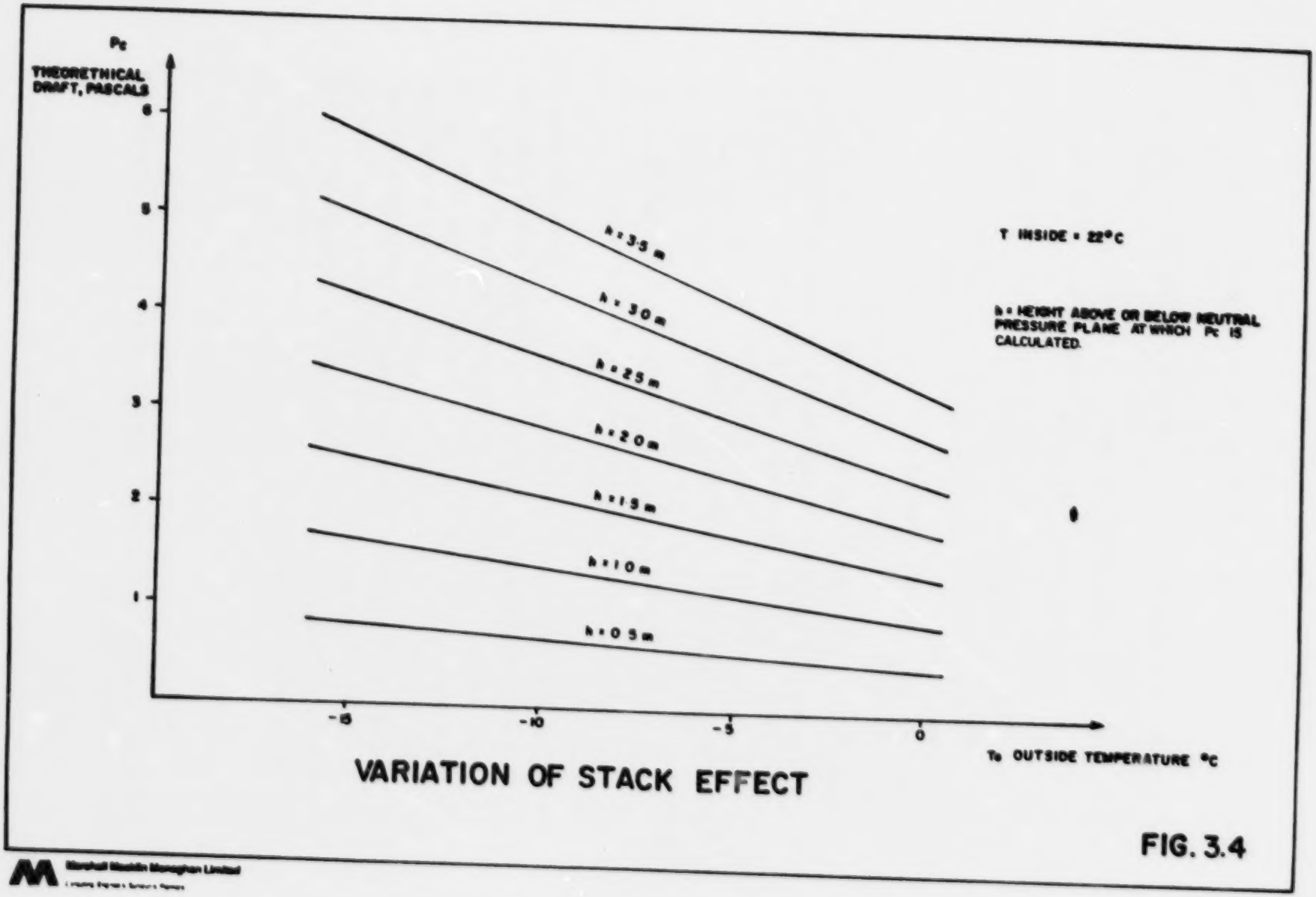
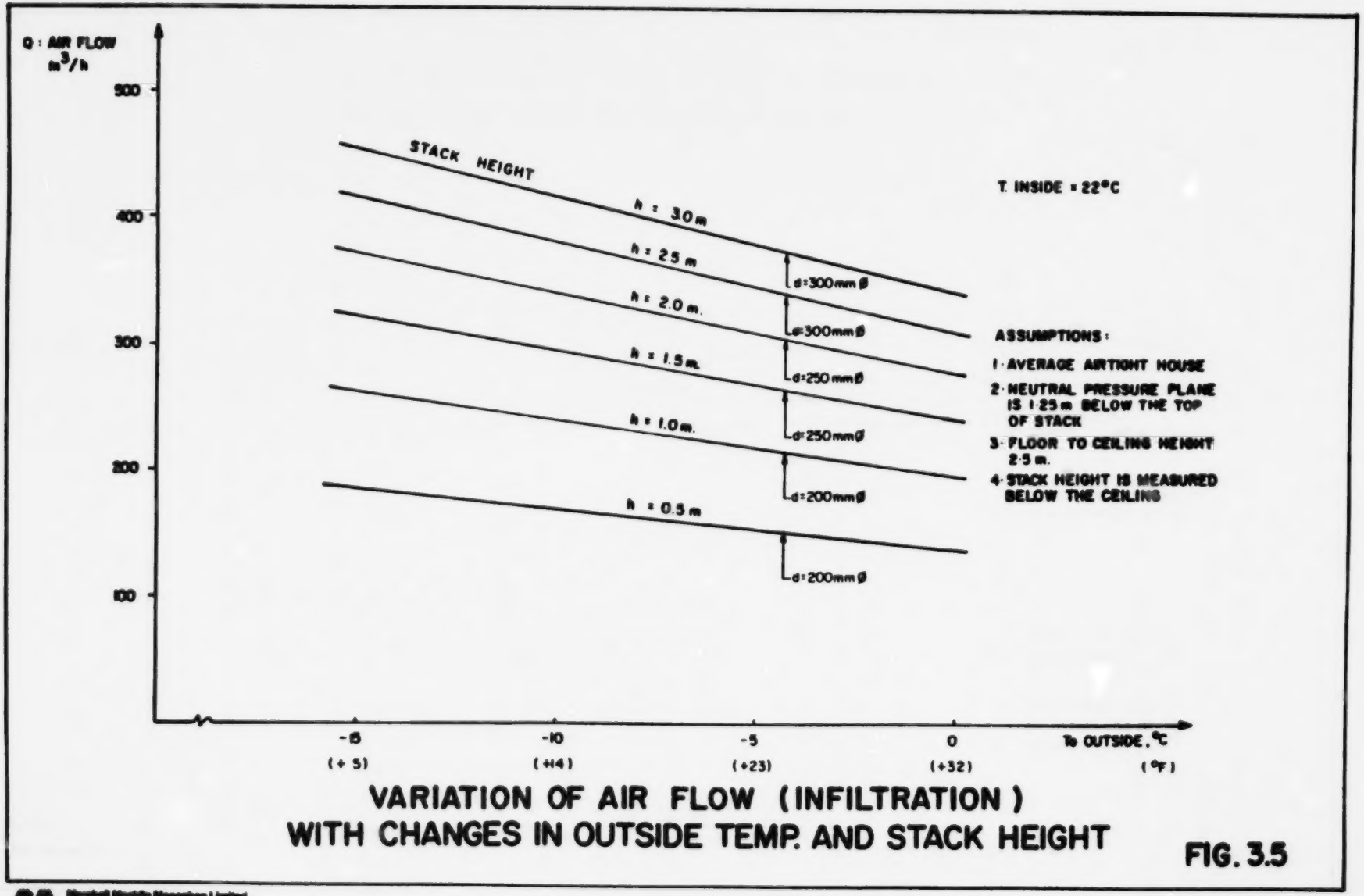
1) Since effective crack area determines the rate of which air can infiltrate, a home with average leakage values at ½ air change per hour has been selected.



VARIATION OF STACK EFFECT

FIG. 3.4



VARIATION OF AIR FLOW (INFILTRATION) WITH CHANGES IN OUTSIDE TEMP. AND STACK HEIGHT

FIG. 3.5

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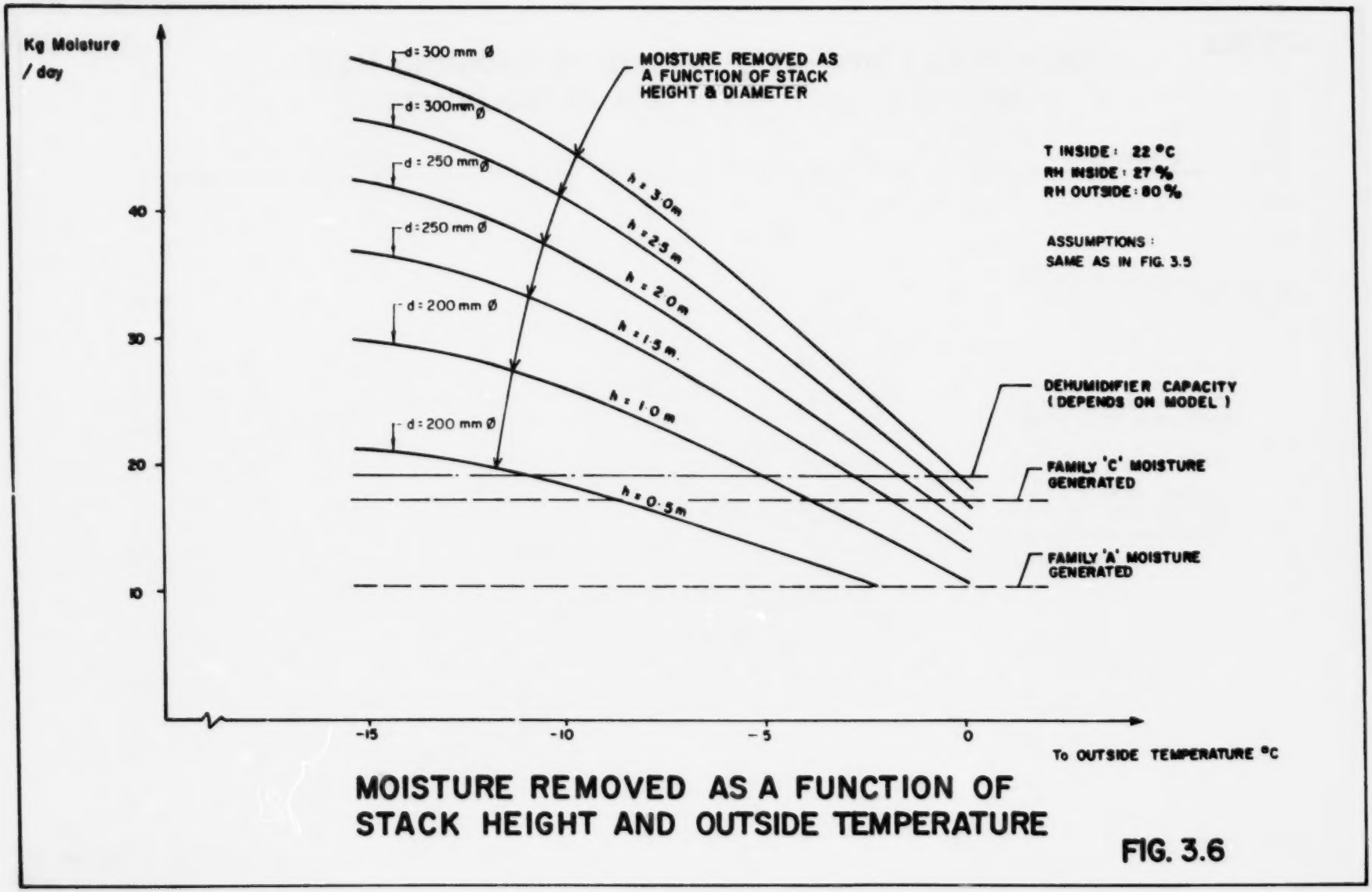

MOISTURE REMOVED AS A FUNCTION OF STACK HEIGHT AND OUTSIDE TEMPERATURE

FIG. 3.6

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Figure 3.6 indicates clearly that, if the effect of wind and the top treatment of the stack are disregarded, as the outside temperature increases to the freezing point, stack heights required for a "typical family of 6 at home all day" approach unacceptable levels (2.5 - 3.0 metres).

The effect of wind, on the theoretical static conditions discussed above, is detailed in the following Section 3.4.3.

3.4.3 Wind Effects on Stack Performance

This section discusses the wind effects on the performance of a passive vent stack and investigates the use of mechanical devices and rain caps to increase stack draft and, therefore, the efficiency of a stack.

Air flow around a building causes a complex pressure distribution. Winds fluctuate in velocity, direction and turbulence and impose varying pressures on the entire structure and within the stack itself. A simple method of analysis, therefore, does not exist for this complex situation. Numerous studies relating to this phenomenon have been undertaken and field tests and wind tunnel tests (scale model) have been carried out.

Available literature[1)] discusses and analyzes all the pressures created by wind in terms of stagnation pressure. Stagnation pressure (at any given wind speed) is defined as the maximum positive increase over ambient pressure that can be exerted on a building surface. The relation between the stagnation pressure and the wind velocity is expressed by the following formula:

---

1) - ASHRAE Handbook, 1981 Fundamentals
- NRC Canadian Building Digest; Wind Pressure on Buildings

$$Pv = \frac{1}{2} \cdot \rho \cdot V^2$$

Pv = stagnation (dynamic pressure, in pascals)
V = wind velocity, in m/s
ρ = Density of air, kg/m^3
= (1.201 for standard air)

Ambient pressure is defined as the pressure of undisturbed free flowing air and is the datum from which all pressures and suctions are measured.

Pressure distribution on a building can range from almost stagnation (Pv) pressure in front of a vertical wall facing the wind, to negative pressure peaks of -5 Pv, as a result of local vortex systems, close to sharp building corners.

External air flow may also cause pressure differences inside the house. The pressure distribution will depend on the location of air leakage openings on the exterior walls. An open window, in the middle of a windward wall, will cause the inside pressure to increase to almost stagnation pressure. An opening on the leeward side will cause the opposite effect.

With a reasonably uniform distribution of small openings, the inside air pressure is, however, not expected to differ by more than 0.2 Pv., throughout the structure[1)].

As air flow is deflected upward by the windward wall, an eddy or cavity zone is created. The height of this cavity zone is proportional to building height and roof slope. A contour zone is also created outside the cavity zone. This area is defined by stream lines deflected by the house. The location of these two zones is shown pictorially in Figure 3.7.

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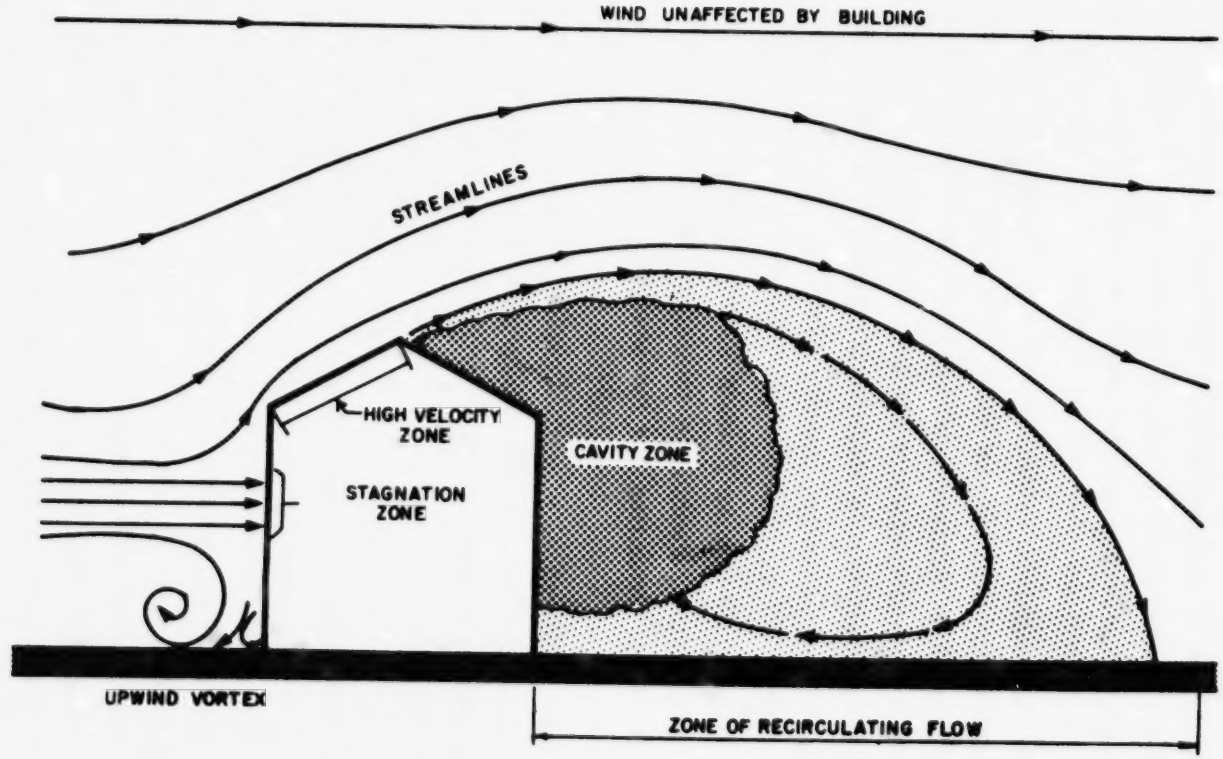
1) NRC, Building Digest; Wind Pressures on Buildings



FLOW ZONES

FIG. 3.7

Depending on the height and location of the stack, air flow over a stack termination can assist or impede stack draft. In regions of stagnation, on the windward side of a wall, or a steep roof,[1] a positive pressure may develop, which will impede the air flow through the stack. Conversely a location in the cavity zone, where negative pressure exists, may increase the stack draft.

As the stack height is extended into the contour zone, the top of the stack is exposed to full wind velocity. Under this condition, wind aspiration, or suction, becomes the dominant force. The actual updraft effect relative to wind dynamic pressure is related to the Reynold's number[2]. This number is a function of air viscosity, density, velocity and stack diameter.

Open top stack termination, while suitable for a large boiler or forced draft system, cannot be tolerated in residential buildings because stack air velocities are too small to deflect rain.

There are a number of, commercially available, mechanical devices or stack cap designs which utilize the wind energy to create additional draft, while at the same time ameliorating the rain problem.

Strong drafts can be created by turbine ventilators, which have blades revolving with wind action. The obvious drawback of such a device is that it introduces a moving part to an otherwise passive ventilation system. Warm, humid air could deposit moisture in the form of ice when it comes into contact with cold metal parts. The possibility of jamming, with the resultant drastic decrease in the effectiveness of the stack, must, therefore, be considered if a turbine ventilator is used.

---

1) A positive pressure is, however, not likely to occur with a normally sloped roof on a low-rise building.
2) ASHRAE Handbook, 1979 Equipment Manual

Passive vent caps are designed to stabilize the wind forces and direct the air upward, creating a suction in the stack. These units are available commercially under different names, such as stack ventilator, syphonventilator, etc.

Depending on the cap design, the pressure difference created is more or less proportional to the velocity pressure of the wind. Unfortunately even the manufacturers do not seem to have more extensive data relating to air flow rates at various different wind speeds. Ideally, each unit should be tested in a wind tunnel for accurate performance evaluation. However, a field trial with proper instrumentation can also provide useful information.

As a guideline, the following table gives the free air flow rates of various inexpensive devices at a 1.8 m per second (4 mph) wind speed.

TABLE 3.2
VARIOUS STACK CAP DESIGNS
FREE AIR FLOW m^3/h (*)

Stack Size (mmØ)	Single Cone Cap	Syphon Cap	Turbine
100	68	110	214
150	85	128	250
200	128	179	434
250	204	323	723

* Source: Various manufacturers' data

The above figures represent free air flow rates without restrictions on the inlet side. In practice, however, much lower air flows will result because of restrictions to air infiltration, particularly in the newer, relatively air tight housing units found in Newfoundland.

The effects of wind on stacks can be summarized as follows:

- Wind forces can affect the performance of a passive vent stack system significantly, but the results cannot be predicted readily without specifying the exact location of the stack and determining, through field tests, the locations of the "cavity" and "contour" zones. Existing guidelines for chimney locations, while assisting in the selection of the more desirable locations, do not always apply to a vent stack. (See Figure 3.7).

- It is best to avoid placing the stack top where stagnation can take place, i.e. in front of vertical surfaces or on a very steep roof. Nevertheless, for a normally sloped roof, it may be desirable to place the stack on the windward side to benefit from the higher wind velocities in this location.

- Unless the stack is located on the windward side of a normally sloped roof to obtain the most assistance from the wind, the stack should be as high as possible. (Height limitations may be imposed by code or design considerations.)

- Stack cap designs that enhance the draft, by utilizing wind energy, are available, and can be used to prevent rain entering the stack. Some of these devices are designed for a flue stack application. Various cap designs must be tested for noise, rain entry and other unpredictable problems, before their large scale use in moisture troubled residences.

- In strong wind conditions, vent caps can create strong drafts, causing high air flow rates through the stack. On cold days, this may introduce so much cold air into a leaky

building that it may be difficult to heat with existing heating systems. An automatic damper mechanism, limiting air flow rates through the stack, should always be used especially if stack vent caps, or other devices utilizing wind energy to enhance draft, are used.

- o Another limiting factor is the airtightness of the house. If stacks are sized for airtight conditions, large volumes will infiltrate when door or windows are opened. Compensating stack controls should be introduced.

3.4.4 Mechanical Ventilation

Mechanical ventilation systems employ a fan, or a combination of fans, to remove air from the house and create a slight negative pressure. These systems can be as simple as a kitchen exhaust fan, or as elaborate as a central exhaust system employing heat exchangers, or other devices for heat recovery.

Advantages of a central exhaust system are; quieter operation, no requirement for openings in ceiling or exterior walls and relative ease of heat recovery. (Heat recovery systems are discussed in Section 3.6 of this report.)

The main disadvantage of the central exhaust system is its capital cost. Because duct work is required, units are also difficult to install in existing houses.

In a house with no basement, the fan may be installed in the crawl space. To avoid several duct passages through the ceiling vapour barrier, the system should not be installed in the attic space as this will permit moist air to enter the attic space when the fan is not in operation.

Some commercially available exhaust systems combine central exhaust with attic ventilation. The basic components of such a system are an exhaust plenum with a fan discharge duct, and exhaust ducts. The plenum is installed in the attic space. Flexible exhaust ducts connect exhaust grilles in the washroom, kitchen, bathroom areas to the plenum. An opening on the plenum, usually with a gravity damper, provides attic ventilation. Such systems create potential problems since the humid air inside the house may escape into the attic space whenever the fan is idle. Although gravity dampers will reduce this flow of air, it is unlikely that they will totally prevent it.

3.4.5 Operating Costs Associated with Ventilation

Moisture reduction through ventilation requires the replacement of moisture laden inside air by cold and drier outside air. Heating this cold air requires additional energy, the cost of which can be substantial if energy recovery systems cannot be utilized.

Energy recovery techniques will reduce the cost of mechanical ventilation substantially, and are discussed in Section 3.6.

Since a passive vent stack depends on the density difference between hot and cold air as the driving force, energy recovery is only possible for mechanical ventilation. (Also, the pressure difference created by a vent stack, even with a draft enhancing cap design, is too small to force air through a heat exchanger coil for airtight houses.)

The mechanical ventilation systems can be classified as follows:

Type 1 - Unitary Exhaust Systems

A unitary exhaust system consists of individual fans venting areas of high humidity, such as the bathroom and the kitchen. The fans are usually of the small propeller type, or occasionally centrifugal units, discharging room air through an exterior wall, or ceiling, through an uninsulated duct. This type of system is the least desirable system of mechanical ventilation for several reasons.

- The fans for this application are usually noisy, and, after connection to any ductwork, generally have low air delivery. Better quality fans are available, but are more costly.

- Discharge ducts pass through the walls and ceilings and present potentially serious breaks in the vapour barriers. When the fan is running the discharge duct is usually positive pressure. A leak in the duct work could therefore force a large amount of moisture into the exterior wall structure or into the attic.

- If the fan discharge duct is not kept above the dew point temperature, condensation within the duct can occur.

- Heat recovery becomes impractical.

Type II - Central Exhaust Systems

The general purpose of a central exhaust system is to control humidity, by collecting humid air as close to the source as possible and, using a centrifugal blower connected to internal ductwork, exhaust the air at one location (usually through the basement wall). Keeping all

ductwork inside the heated portion of the house prevents any possibility of condensation. The system also only requires one interruption of the vapour barrier (located below the neutral pressure plane if basement wall is used).

The exhaust fan may be controlled by a humidistat which starts the fan when humidity exceeds a pre-set, or user controlled, acceptable level.

Because this type of system can create strong negative pressure in the house, it should not be used if combustion devices such as fireplaces and vented stoves are used unless adequate air supply ducts are installed for each combustion device.[1)]

The cost associated with moisture removal depends, therefore, on the amount of moisture to be removed, the inside - outside temperature difference, the relative humidity level to be maintained inside the house , the moisture content of the outside air and the cost per usable KW of fuel necessary to heat the replacement air (currently average costs in Newfoundland are 4.30 cent/KWH).

Based on the ventilation requirements for moisture removal for a "design family" in Newfoundland (Table 3.1), the cost of keeping the inside relative humidity under 30% is calculated and presented in Figure 3.8.[2)]

---

1) This is not expected to be a typical condition in troubled Newfoundland houses.

2) The minimal energy requirements of the fractional horsepower fans associated with mechanical ventilation are disregarded in this analysis.

It should be noted that the cost figures indicated in this chart (Figure 3.8) reflect the total cost of heating all the outside air coming into the house. For an average new house, unless exceptional measures are taken to ensure air tightness, a portion of the air changes, representing 0.5 to 1 air change per hour, takes place naturally because of infiltration. The heat requirement for this amount of air is part of the existing heat requirement of the house. Actual additional costs of ventilation are shown in figure 3.9 and will average from $10-20 per month during the heating season (7-8 months), depending on the average temperature.

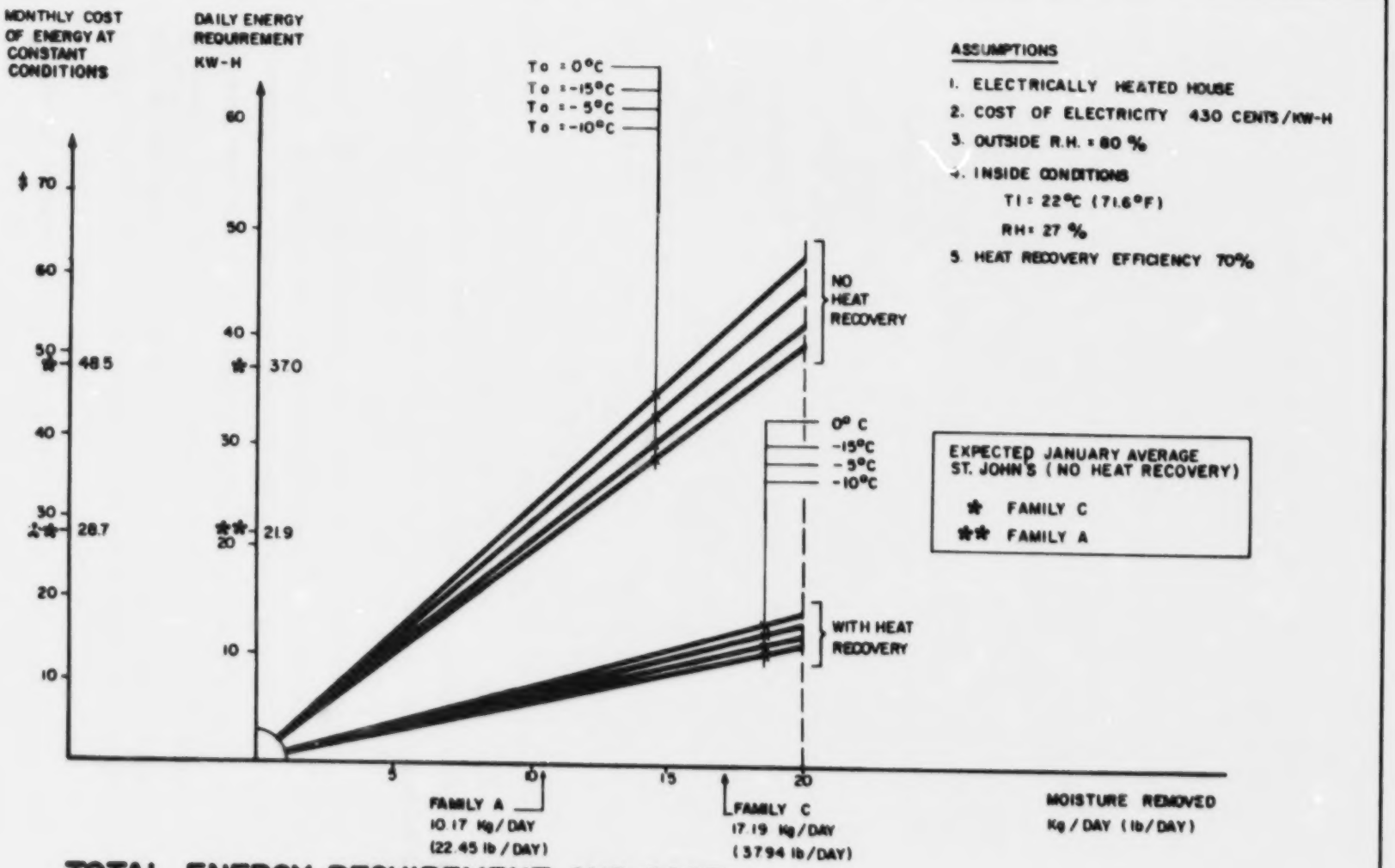
It is interesting to note on Figure 3.8 that a curve reversal takes place when the relatively low vapour pressure of the cold outside air and the energy cost of heating ventilation make-up air are both taken into account. This accounts for the relative position of the various curves for differing outside temperatures.

3.4.6 Conclusion Regarding the Use of Ventilation Systems in Newfoundland

Particularly in Newfoundland, a passive stack for moisture removal and reduction of exfiltration, offers only a limited solution because of practical limitions to stack height and stack diameter.

Stack performance can be improved significantly, in continuous wind conditions such as in Newfoundland, by using special stack caps that utilize wind forces to enhance draft. A number of such devices are commercially available but, since they are not designed for the proposed purpose and a "fail safe" system is required, they should be field tested for suitability in the Newfoundland application (i.e. capacity, control, icing, noise).

The most significant drawback of the stack solution is energy waste.



TOTAL ENERGY REQUIREMENT AND COST FOR MOISTURE REMOVAL BY VENTILATION

FIG.3.8

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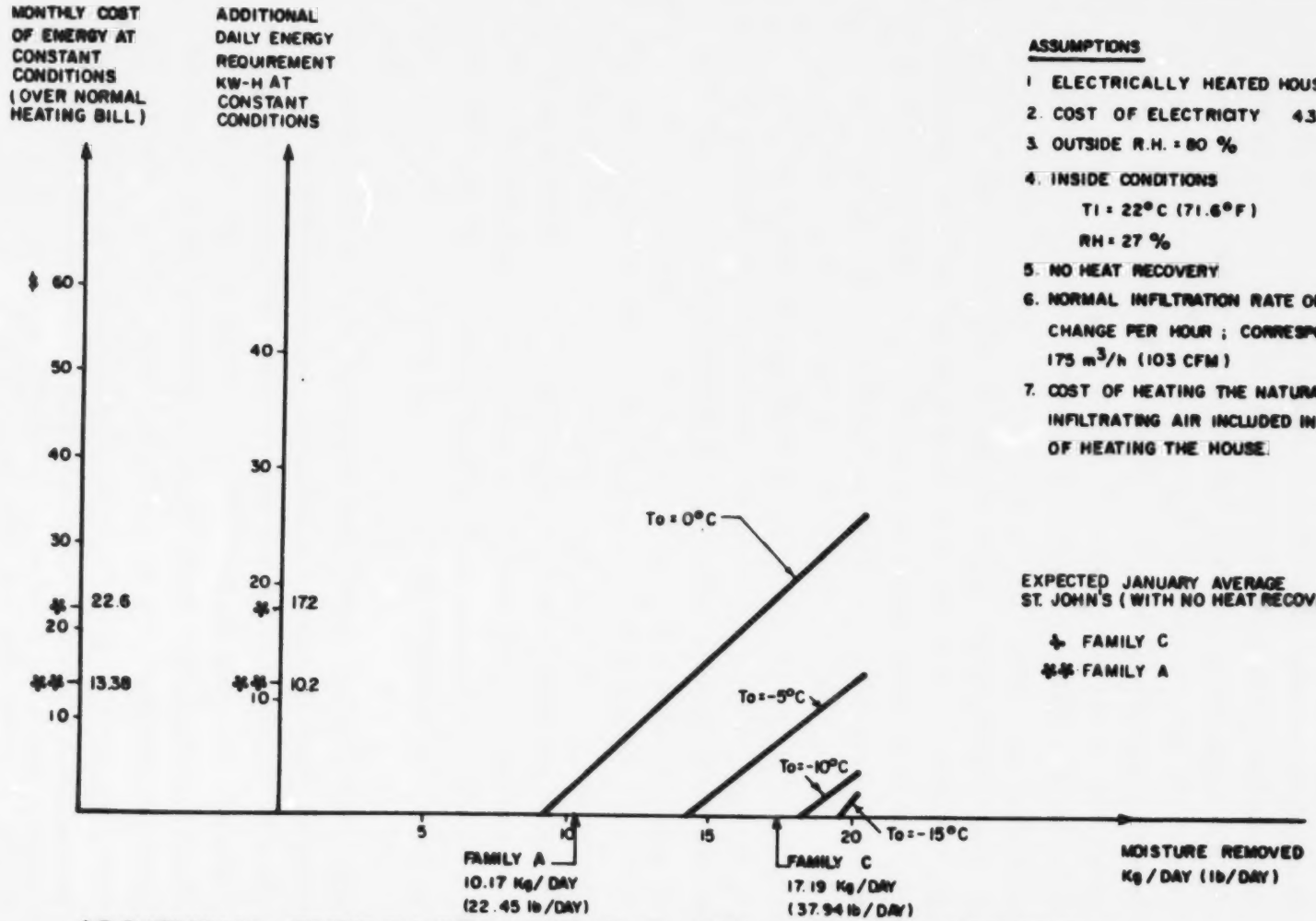

ADDITIONAL ENERGY REQUIREMENT AND COST FOR MOISTURE REMOVAL BY VENTILATION (OVER NORMAL HEATING COST)

FIG.3.9

Mechanical ventilation systems, at varying degrees of complexity, can be used. A simple fan, exhausting air at one point of the house, can, under most circumstances, be sized to provide adequate ventilation but the units are usually small and noisy. Central exhaust systems are the highest in initial cost, but they permit the use of a heat recovery system which will minimize the operating cost of moisture removal by ventilation.

The basic disadvantages of mechanical ventilation systems as compared to a vent stack are that they contain moving parts, create noise, consume some energy to operate and are capital cost intensive. On the other hand, for optimum performance, even a vent stack requires an automatically controlled damper mechanism, also introducing moving parts.

3.5 Refrigeration Systems (Mechanical Dehumidification)

Moisture control by refrigeration differs from ventilation in that it does not depend on dry outside air to remove moisture. With this type of system, to affect dehumidification, moisture laden inside air is drawn by fan over refrigeration coils. Since the coil surface temperature is much lower than the dew point temperature of the air, moisture condenses and drips off into a collection bucket, or is carried off to a drain by a hose connected to a drip tray.

Dehumidifiers for residential use are available at capacities, ranging from 5 to 18 kg per day of water removed at 60% Relative Humidity. Commercially available residential units are designed for high humidity levels. However, their efficiency drops considerably when inside conditions drop below 50% Relative Humidity. It is, therefore, impractical to reduce the moisture content to 30% Relative Humidity levels using only commercially available residential type mechanical dehumidifiers.

Even with a refrigeration system, it would still be desirable to include an exhaust fan or a vent stack to create a slightly negative pressure inside the house and raise the neutral plane. Raising the neutral pressure plane would help to prevent moisture migration into the wall and roof construction.[1)]

All mechanical dehumidifiers employ compressors and small fans and, invariably, generate noise. Depending on the particular unit, these noise levels could be objectionable.

The most important advantage of mechanical dehumidifiers is that there is no net energy cost for removing the moisture. Latent heat of condensing water, plus the electrical energy input to the compressor, is converted to heat and transferred to the air discharging from the dehumidifier. In the winter, this will reduce heat required from other sources by at least an amount equivalent to the surplus energy released over and above the electric energy requirements of the dehumidification system.

3.6 Heat Recovery

Heat recovery is a possible means of reducing the energy penalty associated with mechanical ventilation. Depending on the efficiency of the system, an energy recovery of up to 70% can be achieved by using currently available equipment.

The most common form of heat recovery consists of a central exhaust system, in conjunction with an air-to-air heat exchanger. The heat exchanger itself can be one of the following types:

---

1) Such a system would need to be carefully designed so that outside air enters to prevent the accumulation of harmful pollutants. Also, care must be taken that the reversal does not take place if combustion devices (fireplaces, etc.) are in the house.

- o Fixed surface plate exchanger
- o Tube heat exchanger
- o Rotary type heat exchanger

Other types, such as coil energy recovery loop systems which employ piping, heat transfer fluid and pumps, are available. These systems are, however, not practical for residential applications.

Heat recovery, by means of a heat exchanger, requires an airtight house (¼ air change per hour or less); otherwise a portion of fresh make-up air will enter the house through the cracks and other openings instead of through the heat exchanger, lowering its advantage proportionally. Most commercial heat exchanger packages overcome this problem by providing a fresh air supply fan. Very careful design and installation is required in order not to pressurize the building; otherwise the unit may contribute to the problem it is employed to solve.

Heat recovery, therefore, can reduce the energy loss in ventilation by about 70%. Heat exchangers are quite suitable for new construction, since they need a very airtight house and a central exhaust system. The cost of modifications to existing houses can, however, be prohibitive and is estimated as high as \$4 000 - \$5 000[1]. No attempt has been made to show cost effectiveness, as the simple payback period is in excess of 30 years.

For existing housing, a more suitable heat recovery method would be to employ a small, specially designed heat pump to recover heat from the mechanical ventilation exhaust air.[2] The

---

1) This cost includes required "tightening" of the houses.

2) DSS Contract #OSX 800-00148. A study prepared for the National Research Council of Canada by Hooper Angus and Associates Ltd. entitled "Development of an Exhaust Air Heat Recovery Heatpump".

heat, thus recovered, would be added to the room air after recirculation through the condenser coils. Since the fresh air is not being heated, there is no need to have a separate air intake connected to the unit. Fresh air is expected to enter through the cracks and openings in the building wall as usual.

Heated inside air, discharged from the condenser, would be distributed through small supply grilles.

The main disadvantage of such a heat recovery system is again its high capital cost. Nevertheless, it may still be less costly than the cost of making the house air tight. It is difficult to make any cost comparisons at this point, as commercial units are not available. Given a general acceptance of such a system, the cost could, in our opinion, be brought down sufficiently to make it an economical and practical solution. If it is assumed that a unit of this type could be installed for say $1 000 more than the venting solution where no heat recovery is possible, the simple payback over natural ventilation would be approximately 6 years. This means that the energy savings is sufficient to off-set the additional energy required to heat the ventilation air. As costs of the equipment are lowered, this method would become significantly more attractive.

Regardless of the system used, efficiency of heat recovery systems are limited by frost formation on the exhaust air side. When cooled below the dew point, the moisture in the exhaust air will condense on the cold heat exchanger surface. If the surface temperature is below 0°C, condensate will freeze, restricting the air flow. This problem is more difficult to overcome in fixed plate and tube type heat exchangers than in rotary type heat exchangers. Various techniques have been employed to solve this problem on commercially available units.

As shown in Table 3.3 the frost limit temperature is a function of inside temperature, inside relative humidity and the ratio of supply (fresh air) to exhaust air.

TABLE 3.3

FROST LIMIT TEMPERATURE, T_1

EXHAUST AIR CONDITIONS		FRESH AIR/EXHAUST AIR RATIO	
Dry Bulb Temp. °C	Relative Humidity, %	0.7 T_L °C	1.0 T_L °C
18	30	- 7.8	- 1.0
18	40	-12.2	- 3.4
18	50	-17.3	- 7.1
20	30	-10.3	- 1.5
20	40	-15.6	- 5.3
20	50	-20.4	- 8.6
22	30	-13.0	- 2.8
22	40	-19.4	- 7.3
22	50	-24.8	-16.6

Frosting of exhaust air side coils can be controlled by either preheating the fresh air before it enters the heat exhanger, or by by-passing a portion of it around the heat exchanger.

To give an indication of the impact of heat recovery on the cost of moisture removal, Figure 3.8 also shows the impact of heat recovery if a mechanical ventilation system is used. The values including heat recovery are based on 70% efficiency, or a varying efficiency as governed by the frost limit temperature.

3.7 Capital Cost of Various Moisture Reduction Equipment Solutions

3.7.1 General

This section discusses the approximate cost of equipment and installation of vent stack, central exhaust and heat recovery devices. Lifecycle costs for the venting solution are detailed in Appendix 7. With central exhaust systems, the cost depends on the sophistication of the system, quality of the exhaust fan and length of ductwork. Therefore, the cost figures given here are intended to be representative values only.

There are various types of heat recovery devices on the market. Costs vary over a considerable range depending on the type and manufacturer. These costs are expected to drop as more systems come on the market.

3.7.2 Vent Stack - Capital Costs

As a new installation, the cost of a 250 mm diameter (10") basic stack, stainless steel liner, rockwool insulation, stainless steel case, (commercially available chimney components), length 1.8 m is estimated as follows:

Basic Stack, No Controls

o	Straight pipe, two 900 mm (36") sections	$160
o	Ceiling support	43
o	Roof support	24
o	Joist spacer	16
o	Roof flash	16
o	Storm collar	6
o	Insect screen and flange	10
o	Inlet cone	20
o	Rain cap (stainless steel)	75
	Total Material	$370
	Total Labour	$250
	Total Cost	$620

Additions To Basic Stack Cost

o	On-off motorized damper with humidistat and installation	$300
	Total system cost	$920
o	Modulating damper and humidity controller (proportional)	$650
	Total system cost	$1 270

Costs for retrofit would be somewhat higher, the additional amount being a function of the number of units included in any retrofit contract.

3.7.3 Central Exhaust System - Capital Cost

As a new installation, the cost of a centrifugal fan, motor (2 speed), humidistat, 300 m^3/h (176 CFM), ductwork, grilles, backdraft damper is estimated to be $1 350.

Heat recovery devices, when installed on part of a central exhaust system could increase these costs by $600 to $1 000, depending on the system used. Total costs for a new installation are, therefore, estimated at from $1 900 to $2 500.

As a new installation, including heat recovery, the simple payback over natural ventilation is approximately 14 to 15 years.[1)]

1) Additional capital cost divided by energy saving of 70% of $161.80. (Appendix 7)

3.7.4 Residential Mechanical Dehumidifiers - Capital Cost

Small residential type systems are available at a cost of around $200. However, as mentioned earlier, these are not judged to be of sufficient capacity to be of significant benefit. However, any field test program should include this possible solution.

If compared to the additional energy cost of natural ventilation, the simple payback would be less than 2 years for each unit required.

3.7.5 Exhaust Air Heat Pump - Capital Costs

Although this type of unit may turn out to be a very viable alternative, product development is not enough advanced for an accurate opinion on the capital cost of the unit.

4. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

4.1 Conclusions

The conclusions in this section reflect the calculations contained in the report, findings of the field survey, literature review and research components[1] of this project, as well as the results of the field test undertaken by CMHC in Ottawa, to explore the possibility of utilizing a stack as a method of moisture removal[2].

The field data collected in Newfoundland, as well as that from other parts of Canada, indicate that there is a clear correlation between the relative humidity levels inside the house and the extent of moisture related problems.

Problem houses surveyed by the consultant were subjectively judged to be generally airtight and had electric heating (81% nationally). There were no chimneys or vents in these buildings. Mechanical exhaust systems were mostly in the form of a kitchen range or a bathroom exhaust fan which were not operated continuously. Air change rates will, therefore, be very low and, in most cases, only due to natural infiltration.

Row houses also have less external wall surface available for infiltration; therefore they have an even lower air change.

In any house, hot air tends to rise. Positive pressure is created in the upper floor of a 2 storey house, forcing the humid air through the defects in the upper storey and attic

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1) Parts 1 and 2 of this project, all components of contract 176-4-25 with specific and separate deliverables.

2) Demonstration of Moisture Control by Venting by T.E.S. Ltd. for CMHC Project Implementation Division - April 26, 1982 (CASSELMAN PH I).

vapour barrier. Coupled with poor attic ventilation, this has resulted in high RH readings in the attic space, with a frequently observed attic damage problem (mould and mildew or high moisture readings in structural members).

In light of the survey results, it can be concluded that any solution to moisture related problems must concentrate on keeping lower relative humidity levels throughout the house, while at the same time creating a slightly negative pressure inside the house.

Although the conclusions discussed here refer very specifically to the Newfoundland situation, much of the information is transferable to other areas where similar meso-climatic conditions exist.

- Problem houses exhibit high inside relative humidities. The level of moisture in the air in houses in Newfoundland is both a function of moisture production by the occupants and the fact that outside air entering the system has, itself, a high moisture content.

- Given design ventilation requirements for a typical large family at home much of the time, it is clear that in the Newfoundland situation, a passive stack is not expected to provide adequate ventilation, to drop inside RH to acceptable design levels.

- Although various caps or turbine stack termination treatments are theoretically possible, they must be field tested to prove their usefulness. Stack velocities may turn out to be so high as to require control dampers.

- Notwithstanding the above, passive venting does not lend itself to heat recovery and, in the typical Newfoundland situation, cost penalties averaging up to $20 per month over normal heating costs can be expected ($160 per year 1982 costs).

- A central mechanical ventilation system is a possible solution in Newfoundland but, because of extensive duct work requirements, this solution can probably only be considered for new construction.

- Heat recovery is possible with mechanical ventilation systems. If an air to air heat exchanger is included as part of a central ventilation system monthly operating costs could be reduced by up to 70% of the ventilation energy penalty or approximately $115 per year.

  Capital costs of such a system are, however, high and are estimated at $1 900 - 2 500 for a new installation and could be much higher when retrofit is involved.

- Mechanical dehumidifiers can be used to bring down the extremely high humidity levels observed in some houses to more acceptable levels of around 50% RH. However, it is difficult to reduce humidity levels further by this technique, as the efficiency of this equipment drops considerably when frost formation on evaporator surface becomes a limiting factor.

  With mechanical dehumidification, a small exhaust fan or a passive stack should also be used to achieve slightly negative pressures inside the house to protect the building envelope. Small, capacity units are expected to be available at around $200. (Ref: Various manufacturers.)

However, these units are not very efficient and their applicability will need to be confirmed with a field-test program.

Similarly, a small heat pump could be used to provide adequate dehumidification. Again, reasonable commercial demand would be required before prices would drop to a realistic level. The advantages of using a refrigeration type of dehumidification system are the offsetting of operating costs during the winter by energy gains, as a result of latent heat from condensation. Net operating cost should, therefore, be negligible.

- The above points have dealt with methods of moisture removal. It should be recognized that internal RH in housing units in Newfoundland can be significantly reduced by lowering moisture creation. The authors of this report are of the opinion that reduction in the amount of moisture generated can best be accomplished by means of a public awareness campaign. The public awareness can sensibly deal with such topics as ventilation by opening windows, use of available exhaust fans and lowering basement temperatures to reduce the moisture entering the basement due to ground water problems[1)].

  If all the above changes in living habits are instituted, a significant decrease in inside RH levels will result. (See Table 2.3 "Sources of Moisture".)

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1) The contribution of moisture entering through basement floors and walls is not specifically addressed in this report. It is, however, suspected to be significant, if basements are not properly insulated but are heated. Research in this area is currently being undertaken by CMHC.

4.2 Recommendations

4.2.1 General

The foregoing conclusions lead to a number of recommendations that could be initiated by CMHC.

- Increasing public understanding of moisture, its causes and possible means of reducing its problems. This can be accomplished through a public awareness program.

- Manufacturers should be encouraged to develop products, such as ventilation systems with heat recovery, larger capacity/efficiency dehumidification equipment for residential applications and heat pump applications for use as dehumidification equipment.

- Legislated changes to the insulation program to ensure that insulation retrofits do not create potential moisture related structural and health problems.

- A field test program, in Newfoundland, of the direct applicability of passive stack and other methods of dehumidification. The proposed outline for this field test is discussed in the following section 4.2.2.

4.2.2 Recommendations for Field Research

The objective of Field Research would be to test, in a semi-controlled situation in Newfoundland, the applicability of the various suggested methods of dehumidification.

The tests should be carried out in electrically heated houses common to the area. Tests should be designed to investigate the following:

- effectiveness, of different configurations and locations of stacks, in reducing moisture content levels in typical "troubled" houses;

- effectiveness of exhaust fans in reducing humidity levels in typical "troubled" houses;

- effectiveness of other commercially available dehumidification systems, both singly and in combination with small exhaust fans;

- effectiveness of simple changes in living habits in reducing inside RH levels;

- relative costs/benefits for the various devices tested.

Although these experiments will not permit the identification of a "safe" level of indoor RH, they will determine the ease and costs of lowering RH to various levels in the Newfoundland situation.

The results of this field research would permit the selection of the most suitable cost effective methods of dehumidification, for a given housing type (single family, semi-detached or townhouse), and for a number of typical locational criteria (degree of wind exposure and/or other meso-climatic criteria).

The field research program must include an airtightness test for each house and include necessary adjustments to the airtightness to provide for fully controlled and complete test results and conclusions.

The field research should also look for ways of defining and measuring stack velocity at the stack top at various wind spreads, stack locations and sizes in order to establish location guidelines and performance data.

A possible separate program could be started and run in conjunction with the test work to establish guidelines on air quality requirements in homes, the amount of fresh air needed and desirable.

The effects of high wind spreads around all the houses should be researched and, if possible, a method of forecasting the effects such wind spreads have on the house (pressure, i.e. infiltration, exfiltration, cooling, heating) should be developed.

APPENDIX

1. Calculation of Stack Effect

$$Pc = 0.0342 \times P.h \left(\frac{1}{T_0} + \frac{1}{T_I} \right)$$

Pc: Stack effect (Pascals)

P : Atmospheric pressure

≅ 101 325 Pascals

h: Distance above or below neutral plane, at which Pc is calculated (m)

T_0: Absolute outside temperature, °K.

T_I: Absolute inside temperature, °K.

Pc is calculated for different values of the three variables as below:

T_0: -15°C, -10°C, -5°C, 0°C

T_I: 22°C, 24°C

h: 0.5 m to 3.5 m at 0.5 m intervals.

		h (m)	Pc (Pascals)
1.1	T_0 = 0°C T_I = 22°C	0.5	0.473
		1.0	0.946
		1.5	1.418
		2.0	1.891
		2.5	2.364
		3.0	2.837
		3.5	3.310
1.2	T_0 = 0°C T_I = 24°C	0.5	0.512
		1.0	1.025
		1.5	1.537
		2.0	2.050
		2.5	2.562
		3.0	3.074
		3.5	3.586
1.3	T_0 = -5°C T_I = 22°C	0.5	0.591
		1.0	1.182
		1.5	1.773
		2.0	2.364
		2.5	2.956
		3.0	3.547
		3.5	4.138

		h (m)	Pc (Pascals)
1.4	T_0 = -5°C T_1^0 = 24°C	0.5	0.631
		1.0	1.261
		1.5	1.892
		2.0	2.522
		2.5	3.153
		3.0	3.784
		3.5	4.414
1.5	T_0 = -10°C T_1^0 = 22°C	0.5	0.714
		1.0	1.428
		1.5	2.142
		2.0	2.855
		2.5	3.569
		3.0	4.283
		3.5	4.997
1.6	T_0 = -10°C T_1^0 = 24°C	0.1	0.753
		1.0	1.507
		1.5	2.260
		2.0	3.010
		2.5	3.767
		3.0	4.520
		3.5	5.274
1.7	T_0 = -15°C T_1^0 = 22°C	0.5	0.841
		1.0	1.683
		1.5	2.524
		2.0	3.366
		2.5	4.207
		3.0	5.048
		3.5	5.890
1.8	T_0 = -15°C T_1^0 = 24°C	0.5	0.881
		1.0	1.762
		1.5	2.643
		2.0	3.524
		2.5	4.405
		3.0	5.285
		3.5	6.166

2. Calculation of Infiltration Due to Stack Effect

The most suitable mathematical model for air flow through the leakage area of the building envelope is expressed by the following formula:

$$Q = A\sqrt{\frac{2}{\rho}\Delta p}$$

Q = Air Flow (infiltration)
m^3/S

A = Effective leakage area,
m^2

ρ = Density of air
kg/m^3

Δp = Pressure difference between inside and outside, pascals

This mathematical model has been found to give the most accurate representation of flow in the low pressure range, in the vicinity of 4 pascals. (Infiltration Measurements in Audit and Retrofit Programs, D.T. Grimsrud, R.C. Sonderegger, M.H. Sherman, University of California).

Effective leakage area reflects the air tightness of a building, and mostly depends on the quality of the construction and workmanship. Comparing the published results of previous studies with theoretically calculated figures based as component leakage guidelines (ASHRAE), and the Newfoundland survey, we conclude that a value between 400 cm^2 to 500 cm^2 is typical for the surveyed houses. This represents a fairly airtight house.

For calculations, using 450 cm^2 as effective leakage area and 1.27 kg/m^3 as density of air (at 0° infiltration temperature).

$$Q = \frac{450\ cm^2}{10\ 000} \times \sqrt{\frac{2}{1.27} P_c} =$$

$$Q = 0.0564 \sqrt{P_c}\ m^3/_s \text{ or } Q = 3\ 600 \times 0.564 \sqrt{P_c}\ m^3/_h$$

It is assumed that the leakage area is more or less concentrated at midheight of the building. Therefore P_c is the pressure difference at midheight, or 1.25 m below ceiling when the ceiling - floor distance is 2.5 m.

If we further assume that the stack diameters will be selected to result in neutral plane being 1.25 m below the top of the stack, the actual stack height becomes equal to the distance between the neutral plane and midheight of the house.

3. Calculation of Moisture Removed by Ventilation

$$\text{Moisture Removed} = Q \times \rho \times \Delta m \times 24 \frac{h}{d}$$

Q: Air flow; m^3/h

ρ: Density of air, kg/m^3 (Average 1.25 kg/m^3)

Δm: Moisture content difference of inside - outside air kg/kg dry air.

Using the values of Δm, moisture removed by ventilation has been calculated for Q values on Table A-1 and included in the same table after being converted to kg/day.

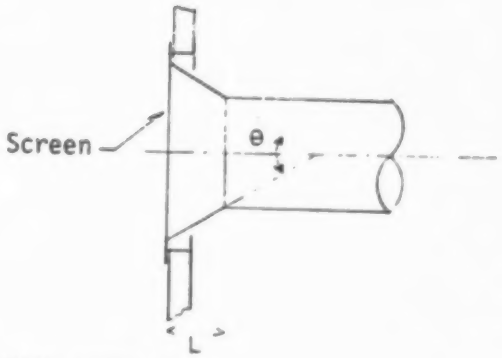
TABLE A-1

Outside Temperature °C	Stack Height m	Pc from calculations (Pascals)	Q: Theoretical Air Flow m^3/h (3600x0.0797 Pc/2)	Moisture removed kg/day
-15	0.5	0.841	186	21.2
	1.0	1.683	263	30.0
	1.5	2.524	322	36.7
	2.0	3.366	372	42.4
	2.5	4.207	416	47.4
	3.0	5.048	455	51.9
	3.5	5.890	493	56.2
-10	0.5	0.714	171	18.5
	1.0	1.428	242	26.1
	1.5	2.142	297	32.1
	2.0	2.855	342	36.9
	2.5	3.569	383	41.4
	3.0	4.283	420	45.4
	3.5	4.997	453	48.9
-5	0.5	0.591	156	13.1
	1.0	1.182	220	18.5
	1.5	1.773	270	22.7
	2.0	2.364	312	26.2
	2.5	2.956	349	29.3
	3.0	3.547	382	32.0
	3.5	4.138	413	34.7
0	0.5	0.473	140	7.6
	1.0	0.946	197	10.6
	1.5	1.418	242	13.1
	2.0	1.891	279	15.1
	2.5	2.364	312	16.8
	3.0	2.837	342	18.5
	3.5	3.310	369	19.9

4. Stack Pressure Losses

4.1 Entry:

Smooth converging bellmouth with end wall (ceiling) and with screen; (75 % free area)



Assumptions

$\theta = 60°$

$L/D = 0.15$

$Co = 0.15$ (ASHRAE)

With screen :

$$Co = Co + \frac{Co'}{(A_1 / A_o)^2}$$

For screen; $Co' = 0.44$

$$A_1/A_o = \frac{D_1^2}{D_o^2} = 2.25$$

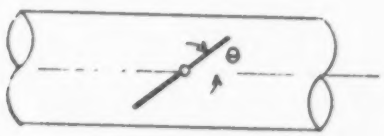
(Assuming D_1 = 300 mm and D_o = 200mm)

$$= 0.15 + \frac{0.44}{2.25}$$

$$= 0.345$$

4.2 Damper; Butterfly, Round

$\theta = 0$ $\qquad C_o = 0.17$



4.3 Discharge: Rain Cap; Discharge loss or regain is neglected. (Conservative approach when wind assisted stack caps are used.)

4.4 Total pressure loss coefficients

$C_o = 0.345 + 0.17 = \underline{\underline{0.515}}$

4.5 P_f : Pressure loss in straight duct; values are taken from ASHRAE duct friction charts.

4.6 Pressure losses in stack are calculated by using the following formulae and shown in table A-2.

Local pressure loss; $P = \Sigma \cdot C_o \cdot Pv$

Pv: dynamic pressure $= \frac{1}{2} \cdot \rho \cdot V^2$ (pascals)

V= Air velocity, m/s
ρ= density, kg/m³
= 1.201 for standard air.

4.7 To find the required stack diameter, the driving pressure difference must be calculated for different outside conditions and stack lengths.

As the neutral plane is 1.25 m below the top of the stack (Our starting point; infinite number of locations can be selected, yielding different results) the portion of the stack effect available for flow through the full length of the stack is calculated below, using the formula on the first page of this appendix.

$P_c = 0.0342\ P.\ h.\left(\frac{1}{To} - \frac{1}{Ti}\right)$

Ti = 22°C

P = Atmospheric pressure; 101325 Pascals

h = 1.25 m

To (Outside Temperature)

°C	Pc Pascals
-15	2.105
-10	1.787
-5	1.479
0	1.183

Stack diameters in fig. 3.5 and 3.6 are sized to result in pressure losses less than or equal to the values above.

TABLE A-2

Pressure loss in stack, Pascals

Pf = Straight duct loss
$\Sigma C_o Pv$ = Local losses

Air Flow		Stack Height	Stack Diameter mm ø											
			150			200			250			300		
m3/h	l/s	m	v m/s	Pf	$\Sigma C_o Pv$	v m/s	Pf	$\Sigma C_o Pv$	v m/s	Pf	$\Sigma C_o Pv$	v m/s	Pf	$\Sigma C_o Pv$
100	27.78	1.0	1.57	0.29	0.76	0.88	0.09	0.24	Too low					
		2.0	1.57	0.59	0.76	0.88	0.18	0.24						
		3.0	1.57	0.87	0.76	0.88	0.27	0.24						
200	55.56	1.0	3.14	0.98	3.05	1.77	0.24	0.97	1.13	0.09	0.39	Too low		
		2.0	Too high			1.77	0.48	0.97	1.13	0.18	0.39			
		3.0				1.77	0.71	0.97	1.13	0.27	0.39			
300	83.33	1.0				2.65	0.49	2.17	1.70	0.16	0.89	0.09	0.24	
		2.0				2.65	0.98	2.17	1.70	0.32	0.89	0.18	0.24	
		3.0				2.65	1.47	2.17	1.70	0.47	0.89	0.24	0.24	
400	111.11	1.0				Too High			2.26	0.29	1.58	1.57	0.15	0.76
		2.0							2.26	0.59	1.58	1.57	0.30	0.76
		3.0							2.26	0.87	1.58	1.57	0.44	0.76
500	138.89	1.0							2.83	Too High		1.96	0.18	1.18
		2.0										1.96	0.35	1.18
		3.0										1.96	0.53	1.18

5. Calculation of Frost Limit Temperature

Frost limit temperature represents the theoretical limit of a heat recovery equipment. Any outside air temperature lower than this value will cause frost formation on the exhaust side surfaces of the equipment.

Frost limit temperature is calculated by reading the available energy of the exhaust air from room temperature to freezing point at 100 % RH from a psychrometric chart. This is equal to:

$$Q = m \times C_p \times \Delta T$$

m: Exhaust air mass flow rate (Here is the ratio of fresh air to exhaust)

C_p: Specific heat of air KJ/kg°C

ΔT: Dry bulb temperature increase (°C) of fresh air.

Then, Frost Limit Temperature

$$T_1 = Troom - \Delta T$$

TABLE A-3

T_1: Frost Limit Temperature

Room Conditions			r= Fresh Air to Exhaust Ratio			
			0.7		1.0	
Dry Bulb °C	RH %	Q* Available Energy kJ/kg	T** °C	T_1 *** °C	T** °C	T_1 *** °C
18	30	17.5	24.8	-7.8	17.4	-1.0
18	40	20.6	29.2	-12.2	20.4	-3.4
18	50	24.2	34.3	-17.3	24.1	-7.1
20	30	20.7	29.3	-10.3	20.5	-1.5
20	40	24.5	34.6	-15.6	24.3	-5.3
20	50	27.9	39.4	-20.4	27.6	-8.6
22	30	24.0	34.0	-13.0	23.8	-2.8
22	40	28.6	40.4	-19.4	28.3	-7.3
22	50	32.3	45.8	-24.8	37.6	-16.6

* : From psychromatric chart

**: $T = \frac{Q}{C_p \cdot r}$ $\quad C = 1.01$ kJ/kg°C

***: One degree °C allowed across H.E. Surface

6. Heat Energy Requirements For Total Ventilation

6.1 Without Heat Recovery

Outside Air db Temp. °C and RH	Moist. Content Difference kg/kg dry air	Ventilation for 10 kg/day Moist. removal, kgAir/day (Note 1)	Q Energy, kW-hr/day (Note 2)
-15 80% RH	0.0038	2631.6	22.15
-10 "	0.0036	2777.8	19.48
-5 "	0.0028	3571.4	20.04
0 "	0.0018	5555.6	23.38
+5 60% RH	0.0013	7692.3	21.58
+10 ≥60% RH	0.	(Note 3)	-

Note 1 = $\text{Ventilation (kg/day)} = \frac{10 \text{ kg}}{\text{Moisture Content difference}}$

Note 2 = Cp of air: 1.01 kJ/kg°C

$$Q = \frac{(\text{Ventilation}) \times 1.01 \times ({}^{T}\text{room} - {}^{T}\text{outside} + 7^{o}C)}{3600} \quad \text{kw-hr}$$

Inside air temperature: 22°C $7^{o}C$ added to outside air temperature to allow for heat gain as air passes through structure, mostly due to solar gain

Note 3 = It is impossible to keep inside RH below 27%

6.2 With Heat Recovery

$T_{outside}$ °C	Q Energy without Heat recovery kW-hr/day	Q with 70% Heat Recovery kW-hr/day	Max. Theoretical Efficiency as limited by frost formation
-15	27.32	8.3	83%
-10	24.94	7.5	100%
-5	27.05	8.1	100%
0	34.29	10.3	100%

Usable energy in exhaust air @ 22°C, 27% RH = 34 kJ/kg (Enthalpy difference to freezing point)

Maximum possible energy recovery : (Dry Heating)

$Q_r = ({}^{T}\text{room} - {}^{T}\text{outside}) \times 1.01$ KJ/kg

Efficiency: $\frac{Q}{Q_r} = \frac{34 \text{ kJ/kg}}{({}^{T}\text{room} - {}^{T}\text{outside}) \times 1.01}$

Room Conditions: 22°C db, 27% RH

7. Life Cycle Cost of A Vent Stack

This section deals with the capital and operating costs of a basic vent stack solution. A typical, 2 m long, 250 mm diameter stack has been considered with the assumptions listed below. Any modifications to the basic design, such as on-off or modulating type damper controls with a humidity controller, increase the capital cost but decrease the operating cost of a vent stack.

Life expectancy of the stack is assumed to be at least 15 years. Total cost is calculated in 1982 dollars.

7.1 Assumptions

- Stack design and house air leakage rates correspond to the air flow rates of a 250 mm diameter, 2 m high stack as shown in Figure 3.6.
- Location: St. John's, Newfoundland.
- Wind enhancing stack caps are not considered. As explained in the report, these would require damper control mechanisms.
- Natural ventilation rate: 175 m^3/h (48.6 l/s).

7.2 Energy Costs

The energy cost increase over the normal heating bill is calculated, based on the average daily low and high temperatures for St. John's Newfoundland are obtained from Environment Canada Data Sources.

Month	Average Daily Low °C (12 Hrs/day)	ΔT, °C	Ventilation Rate Over Natural Ventilation (Note-1) (l/s)	g KWH/hr
Nov	0.2	21.8	90	0.660
Dec	-4.6	26.6	125	1.120
Jan	-7.2	29.2	143	1.407
Feb	-7.9	29.9	147	1.481
Mar	-5.5	27.5	135	1.251
Apr	-2.2	24.2	110	0.897
May	1.1	20.9	85	0.599
			TOTAL ANNUAL	7.415

$$g = \frac{m^3/hr}{3\,600} \times 1.201\ \frac{Kg}{m^3} \times 101\frac{KW}{Kg\,°C} \times \Delta T, °C$$

Month	Average Daily High °C (12 Hrs/day)	ΔT, °C	Ventilation Rate Over Natural Ventilation (Note-1) (l/s)	g KWH/hr
Nov	6.5	-	Not Significant	
Dec	1.6	26.4	80	0.550
Jan	-0.5	22.5	100	0.758
Feb	-1.2	23.2	105	0.821
Mar	0.9	21.1	90	0.640
Apr	4.5	17.5	63	0.371
May	9.7	-	Not Significant	
			TOTAL ANNUAL	3.140

7.3 Expected Cost of Energy Increased at 12%, Discounted at 15%

Year		¢/KW	Energy Cost	Present Worth
0	1982	4.300	161.80	161.80
1	1983	4.816	181.30	157.70
2	1984	5.394	203.10	153.60
3	1985	6.041	227.44	149.50
4	1986	6.766	254.74	145.60
5	1987	7.578	285.30	141.80
6	1988	8.487	319.50	138.10
7	1989	9.506	357.90	134.50
8	1990	10.647	400.86	131.04
9	1991	11.924	448.94	127.61
10	1992	13.355	502.82	124.30
11	1993	14.958	563.20	121.10
12	1994	16.753	630.60	117.90
13	1995	18.763	706.30	114.80
14	1996	21.015	792.20	112.00
15	1997	23.536	886.13	108.90

7.4 Total Combined Cost

Net Present Value of Capital and operating cost of the vent stack for ventilation in Newfoundland over a period of 15 years, in 1982 Dollars:

Capital Cost (from page 38)	$	620.00
Present worth of operating cost	$	2 139.90
Total	$	2 759.90

Notes: 1) From Figure 3-6, minus 175 m^3/h natural ventilation rate.

2) 15% discount rate and 12% escalation costs for energy provided by CMHC.

Total Energy Cost, Yearly (1982)

At Low Temperatures, additional, due to ventilation

7.415 x 12 hrs x 30.5 days = 2615.7 kwh./year

At High Temperatures, additional, due to ventilation

3.140 x 12 hrs x 30.5 days = 1149.0 kwh/year

3765.0 kwh/Year (7 months only)

Cost of Electricity at 4.3 c/kwh (1982)

3765 x 4.3/100 = $161.80 per year

POOR

QUALITY

ORIGINAL